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PERCEPTUAL STRATEGIES OF EXPERTS AND NOVICES IN A FAST BALL SPORT

Bruce Abernethy

A thesis submitted for the degree of Doctor of Philosophy at the University of Otago, Dunedin, New Zealand January, 1986
This thesis describes original research carried out by the author in the Faculty of Physical Education at the University of Otago from June, 1981 to May, 1983 and in the Department of Human Movement Studies at the University of Queensland from June, 1983 to December, 1985.

Bruce Abernethy
This thesis is dedicated to my family and my friends.

To my Mother and Father for their unfailing encouragement, patience and understanding, to my late sister Kay whose influence time can never erase, and to my friends, whose persistent enquiries about the state of this thesis have ultimately provided the necessary incentive for its completion.
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This thesis examined the perceptual strategies of expert and novice badminton players in an attempt to test notions of visual selective attention within applied, ecologically valid, sport settings. In keeping with established premises from information-processing theory it was hypothesized that the expert players would be characterized by a greater ability to extract advance information from the display (to facilitate anticipation), by the allocation of attention to the most pertinent cues available in the display (to promote search efficiency and to avoid distractions) and by the utilization of a relatively low visual search rate (as indicative of processing efficiency).

In Experiment 1 the perceptual strategies of 20 elite and 35 novice badminton players were compared using a series of tasks in which the perceptual display of a badminton player was simulated using film. When the film display was manipulated using variable temporal occlusion points it was found that experts showed a consistently greater ability to predict the landing position of the shuttle from early advance cues than did novices, with the time period between 170 and 85 msec prior to racquet-shuttle contact being a critical one for the establishment of skill group differences. For both skill groups greatest improvements in prediction accuracy arose in the subsequent time period from 85 msec prior to contact to 85 msec after contact implying the criticality of cues arising in this period to the normal decision-making process. When specific spatial cues were selectively occluded from the film display the
racquet and the playing side arm were found to be the principal cues upon which experts based their anticipatory prediction of shuttle direction whereas novices appeared to rely only upon racquet cues. These proficiency-related differences in cue usage were capable of explaining, in part, the differences in anticipatory performance observed on the temporal occlusion task.

Eye movements recorded during the performance of the film task (Experiment 2) were consistent with the notion of the racquet region containing the anticipatory cues of highest informational content with over 70% of all fixations occurring on that section of the display. The visual search sequence was found to normally progress from an early orientation of fixations upon gross bodily features of the opponent (such as trunk, head or lower body) to a later, more precise orientation to the region of the racquet with this apparent proximal-to-distal shift of the fixation distributions matching closely the emergent biomechanical characteristics of the stroke. Both the location and sequence of the fixations however, appeared relatively uninfluenced by the task conditions suggesting that the search patterns adopted were relatively inflexible as if pre-determined by some over-riding perceptual framework. Contrary to some earlier sport-specific investigations of the visual search process no significant differences in fixation location, duration or sequence were observed between experts and novices suggesting that the differences in anticipatory performance observed on the film task were not a consequence of differences in overt visual search characteristics. Advantages of the film task approach over the eye movement recording approach in terms of assessing actual information extraction rather than
merely visual orientation were therefore apparent.

Experiments 3 to 7 sought to establish the validity and reliability of the paradigm for the assessment of individual differences in perceptual strategy used in Experiments 1 and 2. The film task was shown, using dual task methods, to provide comparable attention demands to actually playing and it was shown that concurrent eye movement recording could take place without interference with the subject's response to the film task. Prediction error measures derived from the film task were found to have high reliability with identical conclusions being reached regarding individual subject's perceptual strategies on each occasion the test was administered. Visual search parameters appeared somewhat less reliable with the same anticipatory performance being apparently possible through the use of different search rates, although fixation location and order characteristics remained consistent over time. When the skill group distinction was reduced and an alternative form of error analysis was adopted the characteristic earlier extraction of information and greater utilization of arm cues by experts again emerged, suggesting that the proficiency-related differences observed in Experiment 1 were robust ones.

Finally in Experiment 8 developmental aspects of perceptual strategy were examined through application of temporal and event occlusion tasks to expert and novice players in 12, 15 and 18 year age brackets. Fundamental differences in cue usage in terms of greater dependence upon arm information were apparent for the experts even by age 12 although no concomitant superiority in anticipatory performance emerged until
adulthood. Implications of these proficiency-related differences in perceptual strategy for coaching and talent identification are discussed and some directions for future research, primarily in evaluating the role of the peripheral retina in information extraction, are proposed.
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Appendix O  Publications and associated manuscripts
LIST OF PUBLICATIONS AND ASSOCIATED MANUSCRIPTS

The following is a list of publications and associated manuscripts related to work completed in this thesis. These are incorporated in Appendix B.


A persistent theme of study in motor behaviour has been the search for those factors which discriminate the performance of the elite performer from the lesser skilled. In the case of fast ball sports, the observable differences in performance between the expert player and the novice are substantial and apparent to even the untrained eye. The expert performs in a smooth, unhurried manner with appropriate decisions made both rapidly and accurately and with actions which are characterized by a maximum of efficiency and an apparent minimum of attention and effort. The novice, on the other hand, is apparently forced to constantly operate without sufficient time to determine either what to do or how to do it and the resultant performance is characterized by disorganization and discontinuity. The novice's performance generally reflects an inadequacy to cope with the conflicting demands of both speed and accuracy in decision-making and both consistency and adaptability in movement production.

Historically, detailed descriptions of these observable skill-related differences in performance have been available for many years in the general psychology literature and these descriptions have been accompanied, in most cases, by a clear awareness of the complexity involved within the control processes linking receptor and effector functions. Bartlett, in his classic works in the late 1940's, for example, noted at some length that
There is one characteristic which crops up over and over again in descriptions of expert skilled performance. The operator is said to have "all the time in the world to do what he wants". This has nothing to do with the absolute speed of the constituent movements, bodily or mental. These may be almost incredibly quick, or they may be leisurely and slow. What is impressive is the absence of any appearance of hurry in the whole operation. There is no jerkiness or snatching, no obvious racing to catch up in one part and forced sauntering to make up in another. The "time" that is spoken of is really "timing", and if we could understand the simple timing mechanisms which the human body and mind must obviously be able to use, and how they work, we should have got some way, at least, towards a measure of degree or level of skill.

(Bartlett, 1947, p. 836)

Although the observable differences in skilled and unskilled performance were clearly recognized in the formative years of motor behaviour research the sources of such performance differences were difficult to study because of the covert nature of many of the controlling mechanisms, particularly those responsible for the 'timing' of receptor and effector processes. Understanding of skilled performance was essentially handicapped in these early years by the absence of a conceptual base capable of explaining the vast variance evident in motor skill performance (Weimer, 1977).

The advent of information-processing theory, attributable to the works of Wiener (1948) and Shannon and Weaver (1949) and foreshadowed in the writings of Craik (1947, 1948), provided a major advance in the systematic study of perceptual-motor skills. Information-processing theory advanced the concept that observable motor output was actually the consequence of a series of underlying, sequential stages of information processing occurring within the confines of the central nervous system.
Based on a number of models of these sequential processing stages (e.g. Chase, 1965a, 1965b; Singer, 1968; Welford, 1960; Whiting, 1969) substantial investigation of skilled performance from an information-processing framework was undertaken in the 1950's, 60's and 70's (for summaries see Keele, 1973, 1982) and a substantive data base for understanding human processing capacities and limitations was established.

Unfortunately, in retrospect, many of the experimental examinations of motor skills inspired by information processing theory were of little direct relevance to the problem of determining the critical factors underlying the performance differences evident in 'real world' skills. In order to achieve carefully controlled and quantifiable examination of the underlying information processing stages trivial motor tasks were primarily examined (Neisser, 1976) and output phases of movement skills were studied largely in the absence of pertinent perceptual input (Salmela, 1979). Specifically the important theoretical concerns raised by information-processing theory regarding possible skill-related differences in the efficiency of the underlying control processes were not examined appropriately within ecologically-valid research paradigms (Neisser, 1976; Whiting, 1982; Whitson, 1978) and consequently considerable doubt now exists with respect to the applicability of much of this extant laboratory-derived research. As more applied and ecologically valid research emphases are currently evident in much of the primarily non-English, East European literature than in the North American and English-based literature, recent calls have been made by
leading sport psychologists in both North America (Martens, 1979) and Europe (Whiting, 1982) for greater use of applied field or in situ studies of perceptual-motor skill in sport.

The systematic analysis of sport skills from an information-processing perspective (e.g. see Hammond, 1975; Marteniuk, 1976; Salmela, 1975; Sanderson, 1982), it would seem, however, can still potentially provide a number of benefits toward the development of an overall concept of human performance in fast ball sports as long as an awareness is retained that information-processing theory only provides an analogy to aid in understanding performance in 'real' skills and that precise information-processing structures and functions of the type hypothesized may not exist in actuality within the human perceptual-motor system (Stelmach & Hughes, 1984). Available attempts to apply information-processing notions to understanding the temporal constraints facing the performer in fast ball sports, (e.g. Abernethy, 1981; Drouin & Larivière, 1974; Glencross & Cibich, 1977; Hutt, 1972), for example, appear to be of particular use in the analysis of skilled performance in specific sports. Although caution must be taken in applying laboratory-derived estimates of information-processing latencies, such as simple reaction time, directly to field settings (e.g. see McLeod, 1981, 1982) it can be readily shown that the temporal constraints impinging upon perceptual and decision-making processes are extreme at the highest levels of competition in fast ball sports. Logically the manner in which the

1 - For comparative examination of the applied versus basic research emphases in Europe and North America in cognitive sport psychology generally see either Salmela, 1981, 1984; Vanek and Cratty, 1970 or Williams, 1982.
limited time available for environmental analysis (perception) and response-selection (decision-making), is utilized by the performer may be critical in determining response efficiency and in turn performance levels. Consequently, in view of Bartlett's notion of the skilled performer having 'all the time in the world' an important focus for sport science research has become the comparison of the manner in which expert and novice performers use the limited display available to them to derive accurate and rapid response selection information.

Initial searches for skill differences in sport perception took an essentially 'hardware' approach, searching for identifiable 'hard-wired' visual-perceptual attributes capable of discriminating the expert from the novice. Measures of response latency such as reaction time (e.g. Bhanot & Sidhu, 1979; Knapp, 1961a; Rotella & Bunker, 1978) and nerve conduction velocity (e.g. Hoyle & Holt, 1983; Street, 1968), optometric parameters such as static (Banister & Blackburn, 1931; Winograd, 1942) and dynamic (e.g. Morris & Kreighbaum, 1977; Sanderson, 1972, 1981) visual acuity, depth perception (e.g. Cockerill, 1981a; Miller, 1960; Zimmerman & Lane, 1976), peripheral visual range (e.g. Cockerill, 1981b; Stroup, 1957; Williams & Thirer, 1975) and reactivity (Buckfellow, 1954; Young & Skemp, 1959), colour vision (e.g. Cobb, 1967; Cockerill & MacGillivray, 1981; Gavriysky, 1969, 1970) and ocular muscle balance (e.g. Graybiel, Jokl & Trapp, 1955; Ray, 1972) and perceptual style tests such as field dependence-independence (e.g. Bard, 1972; Barrell & Trippe, 1975; Pargman, Schreiber & Stein, 1974; Williams, 1975, 1980) were employed with great frequency, but the outcome in terms of clear discrimination of skill groups was, in the main, equivocal. Although
visual attributes of the type mentioned are undoubtedly important in sports performance they are unlikely to clearly discriminate skill groups because of the inherent multivariate nature of visual-perceptual performance in sport and because of the possibility of performers compensating poor performance on one 'hardware' variable with proficiency on another attribute (e.g. see Clarke, 1971, p. 255). Hardware variables of the type examined in these early studies may well set the theoretical limits of visual performance within a particular sport but efficient performance clearly requires more than simply possessing the necessary 'mechanical apparatus' for the extraction of task-relevant visual information (Abernethy & Russell, 1983; Rothstein, 1977a).

Although the search for discriminating hardware variables is still the persistent focus of many research (e.g. Blundell 1984; Mizusawa, Sweeting & Knouse, 1983) and clinical (e.g. Getz, 1978; Harrison & Reilly, 1975; Revien & Gabor, 1981) energies, a more promising line of contemporary research is with the search for 'software' variables discriminating the information-processing capabilities of highly skilled and lesser skilled performers (Starkes & Deakin, 1984). Unlike 'hardware' variables, which are essentially 'hard-wired' mechanical attributes of the individual's visual-perceptual apparatus, the investigation of 'software' variables focuses upon the 'programs' and 'strategies' the individual performers use in order to operate efficiently within their particular 'hardware' constraints. Specifically applied studies are now available from both laboratory and field settings showing greater capability of expert sport performers...
(a) to anticipate forthcoming events from advance information sources (e.g. Abernethy & Russell, 1984; Day, 1980; Isaacs & Finch, 1983; Jackson, 1985; Jones & Miles, 1978; Patrick & Spurgeon, 1978; Soulière & Salmela, 1982; Starkes & Deakin, 1984)

(b) to extract information regarding event probabilities to facilitate response speed (e.g. Alain & Proteau, 1980; Cohen & Dearnaley, 1962; Régnier & Salmela, 1980a; Schubert, 1981; Whiting, 1979)

(c) to recognize situation structure and redundancy within the perceptual display presented by an opponent (e.g. Allard, 1982; Allard, Graham & Paarsalu, 1980; Allard & Starkes, 1980; Borgeaud & Abernethy, 1985; Starkes & Allard, 1983; Starkes & Deakin, 1984)

and (d) to effectively share time and attention between two or more concurrent tasks (e.g. Keele & Hawkins, 1982; Leavitt, 1979; Parker, 1977, 1981).

The apparent success of studies of this type in discriminating proficiency levels supports the view that a valuable line of research within sport psychology may be to examine the strategies adopted by individual performers in response to the specific information processing demands of the sport environment (e.g. see Singer & Gerson, 1981) and this contemporary sport focus parallels the growing interest in the examination of strategies within discipline-based cognitive psychology (e.g. see Kail & Bisanz, 1982).

Given that the study of strategies is important there is undoubtably no more crucial strategy in fast ball sports than the perceptual strategy which is used to guide the process of visual selective attention i.e. that control process concerned with how individuals reduce the existing environmental information to manageable quantities through the selective processing of only pertinent information. The available evidence
demonstrating differences in anticipatory performance (e.g. Jones & Miles, 1978) suggests that there may be fundamental differences in the manner in which experts and novices in fast ball sports allocate their limited visual attention to the perceptual display. Specifically the evidence would suggest that there may exist critical differences in the range and location of cues used by the two skill groups in first analyzing the display and in then reaching appropriate response-selection decisions.

Although logical predictions regarding differences in visual attention allocation can be drawn from existing theoretical models of selective attention\(^2\) (e.g. Norman, 1969) and some laboratory-based studies isolating differences in cue usage dependent upon proficiency level have been reported (e.g. Fuchs, 1962; Garvey & Mitnick, 1957), differences in the perceptual strategies of experts and novices in 'real' skills, especially fast ball sport skills, have been only very scantily examined from a scientific perspective. The only direct evidence examining perceptual strategies in sport comes from a handful of studies initially from the Canadian sport scientists Bard and Fleury at the University of Laval, (Bard & Fleury, 1976a, 1976b, 1976c, 1981; Bard, Fleury, Carrière & Hallé, 1980; Bard, Guezennec & Papin, 1981; Ripoll, Bard, Paillard & Grosgeorge, 1982) and more recently from European sources (e.g. Haase & Mayer, 1978; Neumaier, 1982; Ripoll, Papin & Simonet, 1983; Ritzdorf, 1983), in which visual search pattern recordings of expert and novice performers have been made. Although conclusions

2. Indeed skill acquisition is occasionally defined in terms of improved selective attention (e.g. see Girouard, 1980)
have been reached by these authors indicating proficiency-related differences in terms of cue usage, as implied from ocular fixation location data, and visual search rate, as implied from fixation duration data, the evidence supporting these conclusions has been, in the main, quite tenuous. The existing studies are of small sample size, and hence statistical power, and are, more importantly, fraught with problems of restricted ecological validity. Most obviously many of these studies are of limited 'real-world' applicability because they frequently use static two-dimensional display stimuli (such as slides) to represent the dynamic three-dimensional display of the natural setting, they fail to apply realistic temporal and attentional constraints of the type encountered in actual skills and they use response modes which are quite unrelated to the form of motor response which must be elicited in the intact skill. Moreover, although many of these paradigm limitations may arise as a consequence of the constraints imposed upon subject mobility by the existing eye movement recording techniques (see Monty & Senders, 1976; Young & Sheena, 1975a, 1975b) there is a general neglect in the applied visual search literature to consider any of the inherent methodological assumptions accompanying eye movement recording. Specifically there is a failure in the existing literature to consider the problems of implying visual attention allocation from only fixation location data, when it is known that attention can be moved throughout the visual field in the absence of eye movements (Gippenreiter & Romanov, 1974; Posner, 1980; Shulman, Remington & McLean, 1979; Sperling & Reeves, 1980), and there are anomalies apparent in the literature with the use of fixation duration as an indicant of information-processing load (e.g. compare the

The specific difficulty withholding the advancement of sport-specific research on perceptual strategies in sport is therefore the current absence of an appropriately validated test of selective attention specifically designed for use in fast ball sports. The existing methodologies for examining visual selective attention in sport are of low ecological validity, are reliant upon the results of one dependent measure rather than utilizing cross-validation from data derived through a number of media, and are generally inappropriately established with respect to reliability, objectivity and validity. Furthermore the methodologies and research paradigms used are principally borrowed from other disciplines rather than developed specifically to meet the requirements of the sport environment. In this respect it should be noted however that the parent discipline of Psychology is also struggling to establish an appropriate form of visual selective attention test (e.g. see Avolio, Alexander, Barrett & Sterns, 1981; Irwin, 1979) with current tests primarily involving simple modifications to the original dichotic-listening tasks (e.g. see the selective attention tests for pilots by Gopher and Kahneman, 1971 and car drivers by Kahneman, Ben-Ishai and Lotan, 1973 and Mihal and Barrett, 1976).

A fundamental concern, then, would appear to be with the establishment of an appropriate sport-specific paradigm to allow knowledge of selective attention/perceptual strategies in fast ball sports to be acquired through generated rather than recipient sources
It is the purpose of the present thesis to address this concern whilst examining the source of proficiency-related differences in the perceptual strategies used in one selected fast ball sport, viz badminton.

The present examination of skill group differences in perceptual strategy therefore proceeds in the following manner:

In the next chapter (Chapter 2) the literature relating to information processing in skilled movement production is reviewed in order to develop an operational model of the cognitive processes active in fast ball sports. This model is developed with the specific objectives of (a) providing insight into the potential cognitive structure underlying skilled performance and of (b) providing an approximation of the time constraints under which the various processing stages are forced to operate. Chapter 3 then examines the existing knowledge regarding selective attention and visual search processes, based primarily on laboratory findings, and advances, on the basis of this review, a number of hypotheses regarding potential sources of difference in the perceptual strategies of experts and novices in fast ball sports. Potential paradigms for the assessment of these perceptual strategies are examined and evaluated in Chapter 4 resulting ultimately in the selection and development of a multi-procedural approach for ongoing study of sport-specific visual selective attention. This developed paradigm, which incorporates selective temporal and spatial occlusion of display information with concurrent eye movement recording, is then used in Chapter 5 to examine experimentally these earlier
theoretical notions regarding proficiency-related differences in perceptual strategy.

Chapter 6 sets out to establish the validity and reliability of the proficiency-related differences in perceptual strategy obtained in Chapter 5. The problem of validity and reliability is addressed by (a) examining the concordance between the workload (attention) demands of the test task and the actual playing task and by (b) examining the robustness/reliability of the observed effects over differences in time, skill level differentiation and response mode selection. Finally age differences in the development of perceptual strategies by experienced and novice players are examined in Chapter 7 utilizing the paradigm selected, developed and validated in the earlier chapters.

The global objective of the present thesis is therefore to extract knowledge regarding the respective perceptual strategies of expert and novice performers in fast ball sports which is of both theoretical and practical importance and which provides a basis for directing ongoing vision and sport research. Some of the future research directions arising directly from the results obtained from studies in this thesis are briefly considered in Chapter 8.
CHAPTER 2

COGNITION AND INFORMATION PROCESSING IN FAST BALL SPORTS

Although the study of motor behaviour began with an interest in the study and advancement of performance in "real-life" skills (e.g. Bryan & Harter's 1897, 1899 work on telegraphic and morse code skills and Book's 1908, 1924 work on typing skill) motor behaviour in the post-War years has been dominated by 'basic' research using very simple motor tasks and concerned primarily with theoretical notions related to motor memory and control (Salmela, 1979). In keeping with this trend reviews of current and future directions for motor behaviour research frequently make little mention of perceptual processing in 'real' skills as an important contemporary issue (e.g. see Stelmach, Diggles, Szendrovits & Hughes, 1981).

Although 'basic' research using simple motor tasks serves important functions, especially in terms of isolating the nature of the control processes underlying the production of skilled movement (Russell & Abernethy, 1979; Schmidt, 1975, pp. 18-19; Tyldesley & Whiting, 1975), there exists a constant need to relate theoretical notions back to practice and to conduct applied research on 'real' skills (Singleton, 1979; Warr, 1973). Within the traditional domains of sport psychology at least, there appears a growing awareness of the importance of applied research, with its field rather than laboratory orientation.

3. For historical reviews of the development of the field of motor behaviour see Spirduso, 1981 or Schmidt, 1982a, pp. 8-19.
(Martens, 1979; Salmela, 1979; Whiting, 1982), although researchers in skill acquisition appear a little slower in making this re-orientation (e.g. see Salmela, 1982; Stallings, 1982). Of particular interest in this thesis is the application of many of the theoretical notions related to information processing, especially those of selective attention, to the understanding of human performance in a class of 'real' skills, frequently referred to as 'open' skills (after Poulton, 1957). Specifically the interest is with ascertaining the origins of the vast individual differences which are evident in the performance of 'open' skills and with detailing the effect that the level of expertise has upon information-processing within these skills. This chapter serves to review the application of the Information-Processing model to 'open' skills in some detail and proposes an operational model which allows the temporal constraints in fast ball sports to be examined from a processing perspective.

1: THE INFORMATION PROCESSING MODEL

Origins and Basis of the Information Processing Model

Originating out of the works of Craik (1947, 1948), who provided the conceptual base, and Wiener (1948) and Shannon and Weaver (1949), who collectively provided the mathematical base, Information Processing theory is based on the analogy of the human performer to a high-powered communications system deriving, as it does, input information from the environment, performing some central processing on the input and converting it eventually, in turn, to meaningful output. The modern
information-processing approach draws heavily on the analogy of cognitive processes to the mode of operation of the computer (Neisser, 1976) and many of the terms now used freely in the analysis of human cognition and motor processes (terms such as input, coding, processing, sub-routines, executive programmes etc.) have computer science origins (Stelmach, 1982).

The theory of information processing essentially necessitates a process-oriented approach to examining perceptual-motor skills (Kelso, 1982a) with emphasis being directed towards the capacities and limitations in the various processing stages underlying skilled movement production (Marteniuk, 1976). Given the availability of procedures for quantifying information content and transmission provided by Shannon and Weaver's work (see more recently Fitts & Posner, 1967, pp. 85-92; Coombs, Dawes & Tversky, 1970, pp. 307-350; Keele, 1973, pp. 58-74 or Wickens, 1984, pp. 57-67) it is not surprising that a strong initial research thrust developed in the direction of attempting to quantify the information processing capacities and limitations of various stages of processing (e.g. see Fitts, 1954; Miller, 1956; Welford, 1976). A parallel and related research problem to that of capacity determination was with the identification of the discrete processing stages hypothesized as acting in the translation of the input information in the environment to the movement output observed and measured by the researcher. It is with the determination and identification of these central processing stages that the majority of assumptions underlying information processing theory are made. Specifically the principal assumptions underlying the information processing model are, according to
Stelmach (1982), the assumptions that:

1. Numerous processing stages occur between stimulus and response.

2. The sequence of processing stages is initiated by stimulus presentation.

3. Each stage operates only on information available to it.

4. Each stage transforms in some way the information supplied to it, an event which requires time for accomplishment.

and, 5. Upon completion of processing performed at one stage, the transformed information is made available to the next stage of processing.

(p. 66)

As the built-in arrangement of the processing stages identified determines the potential pathways or routes available for information flow (Neumann, 1984) the models of the intervening processing stages which emerged as information processing theory developed became increasingly complex (e.g. see Robb, 1972, pp. 30-36) and varied considerably in terms of the number and hypothesized function of the central processing stages. Amongst the information processing models which emerged in the 1960's and 70's (e.g. see Chase, 1965a, 1965b; Crossman, 1964; Gentile, 1972; Poulton, 1970; Rothstein, 1977b; Singer, 1976; Welford, 1960) there were, however, a number of common features. Each of the models, for example, proposed a general processing direction which involved the passage of information from perception through response selection to effector or response organization and each incorporated a number of feedback and error-correction loops to allow performance to be adaptive. Frequently a number of the underlying
processing stages were grouped together into hypothesized structural mechanisms (see Singer, 1980a) and, more recently (following Atkinson and Shiffrin's 1968 differentiation of control processes from structural features) theorists have gone to considerable lengths to specify how the existing control processes determine the appropriate processing route within these structural constraints (Metz, 1974). Considerable research energies have also been directed towards attempting to validate the stage structures utilized in the various models, both in terms of the independence of the processing stages (using the additive factor methodology advanced by Sternberg, 1969) and in terms of whether the existing processing stages are automatic or attention-demanding (La Berge, 1981; Neumann, 1984; Shiffrin & Schneider, 1977).

More detailed consideration of one of the more influential information-processing models (Welford's, 1960, 1965, 1968 Human Performance Model) provides a useful insight into the possible covert information-processing stages which may underlie the production of skilled movement and into the procedures which may be used in examining the efficacy of the structure and predictions of the Information Processing model generally.

**An Example of an Information Processing Model: Welford's (1960) Human Performance Model**

Welford's basic model of human performance, which has since been adapted and modified by a number of authors (e.g. Marteniuk, 1975, 1976; Stallings, 1976, 1982; Whiting, 1969, 1972) suggests the existence of three covert processing mechanisms between the overt events of stimulus
Figure 1: The Human Performance Model (adapted from Welford, 1960 and Whiting, 1969)
reception and movement (response) initiation, and associated with each of these structural mechanisms are a number of distinguishable control processes. (See Figure 1).

The first of these central processing mechanisms, the perceptual mechanism, functions in primarily reductional, interpretational and organizational roles, taking in large amounts of input information from the various sensory receptor groups and selecting out from this maze of current information only that information which is most relevant or pertinent to the task at hand. The principal function of the perceptual mechanism is then with the transformation of this raw data from the receptors into interpretable percepts (Haber, 1969), which provide the performer with a clear indication of the existing environmental conditions. This transformation involves a series of ordered processes ranging from detection through discrimination and recognition to stimulus identification (Sage, 1984, p. 111).

Information from the perceptual analysis is then passed in turn to the decision or translatory mechanism which is responsible for deciding upon what course of action, if any, is required to fulfill the performer's current movement objectives. The decision mechanism is therefore primarily concerned with the process of response selection - a process which, like those in the perceptual mechanism, may be influenced substantially by the performer's prior experience and expectations.

If the analyses performed in the decision mechanism result in the selection of a plan of action which differs from the performer's existing
state, information is then passed to the third of the processing mechanisms, the effector mechanism, which is responsible for organizing the desired movement response in terms of its hierarchical, sequential and temporal components (e.g. see Glencross, 1978a, pp. 60-66). A series of efferent neural commands is then ultimately issued from the effector mechanism to the muscle groups selected for the movement and this results, in turn, in the contraction of the selected muscle groups with the relative force and timing specified in the efferent commands (Evarts, 1968, 1975). Whether the neural commands from the effector mechanism are totally pre-specified and issued in a single 'package' as a motor program (Keele, 1968) or are released intermittently and continually updated on the basis of intrinsic (proprioceptive) feedback arising from the movement, appears to depend to some extent on the duration of the action, the predictability of the environment, the state of skill acquisition, and the preferred mode of motor control of the individual performer (e.g. see Klapp, 1975; Schmidt, 1980, 1982b). (Further elaboration of the respective functions of the three central mechanisms and their associated control processes may be found in Marteniuk, 1975, 1976; Sharp, 1973; Stammers & Patrick, 1975; Whiting, 1969, 1972 or Wright, Taylor, Davies, Sluckin, Lee & Reason, 1970).

Some support for the processing stage structure implicit in this particular information-processing model can be gained from examination of studies of processing stage independence emanating from Sternberg's (1969) additive factor methodology. The additive factor method, which is an extension of the early subtraction method for studying stages in reaction time proposed by Donders in the 19th Century (Donders, 1868),
essentially involves examining the additive and/or interactive effects of two or more concurrently manipulated factors, each of which are known to have an effect upon reaction time. The basic logic underlying the method is that if two factors influence the same information-processing stage then their concurrent manipulation should lead to interactive effects primarily because the two factors are forced to compete for limited processing resources within a common stage. On the other hand, when additive effects are observed in the factorial analysis of variance, it is assumed that no competition for common information processing resources has arisen and consequently it is concluded that different processing stages are affected by the two factors. (For examples of additive and interactive effects see either Sternberg, 1969 or Stelmach, 1982).

Although the additive factor method has a number of quite substantial limitations and assumptions (Pieters, 1983; Sanders, 1980; Smith, 1968; Townsend, 1972, 1976), it provides a method of 'empirical investigation of central nervous system functioning that would otherwise remain encapsulated in a general performance latency' (Tyldesley, 1981, p. 96). Even though no inferences regarding the order or temporal duration of the stages involved in rapid information processing can be drawn from either Sternberg's original method or from more recent modifications (e.g. Taylor, 1976), the mass of research conducted using additive factor methods provides a useful avenue for deriving at least some partial support for the structure used by Welford in his model of human performance. Existing summaries of the additive
Figure 2: Additive factors and processing stages in Welford's (1960) Human Performance Model (Based on data presented in Sanders, 1984, p. 243 and Wickens, 1984, p. 368).
factors literature (Sanders, 1980, 1983) suggest the existence of at least four to six discrete processing stages and although the naming of these stages is quite arbitrary, the identified stages equate well with the processing stages implicit in the Welford model (see Figure 2). The perceptual mechanism proposed in Welford's model, for example, can be seen to incorporate the independent stages of stimulus pre-processing, feature extraction and identification derived from the additive factors literature, the decision mechanism can be seen to contain the arbitrarily defined response selection process whereas the independent states of response programming and motor adjustment can be seen to fall under the structure of Welford's effector mechanism.

**Assessment of the Utility of the Information-Processing Approach**

Information processing models, such as Welford's, enjoyed quite universal acceptance in the motor behaviour literature⁴, and in the experimental psychology literature generally (e.g. see Massaro, 1975; Solso, 1975), from the time of the model's conception in the late 1940's through into the 1970's and early 80's. Although some minor difficulties in the mathematics of information processing theory have been alluded to for some time (e.g. see Wickens, 1984, pp. 65-67) it is only recently that any substantial opposition to information-processing notions has been advanced, and this has come primarily from motor control and cognitive psychology sources. Specifically a number of motor control

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⁴ The dominance of the information processing approach in motor behaviour research up until the late 1970's is most evident in perusal of the three edited texts on motor control by G. Stelmach which emerged in that period (Stelmach, 1976, 1978, 1980).
theorists have drawn objection to the hierarchical organization of movement control implicit in the information processing perspective citing the now considerable evidence to illustrate that much of the control previously attributed to the central processing of information is actually inherent in the dynamics of the lower regions of the central nervous system and in the oscillatory properties of the muscles themselves (Asatryan & Feldman, 1965; Bizzi, 1980; Kelso, 1977; Turvey, Shaw & Mace, 1978). A number of alternatives to the traditional 'top-down' organization of movement in the information-processing model are now proposed (Stelmach & Hughes, 1984), most particularly 'bottom-up' notions of movement control, which view movement as an emergent consequence of the underlying muscle dynamics rather than the outcome of centrally planned neural commands (e.g. Kelso, 1981; Kelso, Holt, Rubin & Kugler, 1981). Cognitive theorists have criticized primarily the rigid structural notions which were evident in many of the early information processing models and now direct their attentions more toward the control processes than to the hypothesized structural mechanisms (Stelmach & Hughes, 1984). This structural de-emphasis has resulted in the increased popularity of resource models rather than stages models of human performance (e.g. see Gopher & Sanders, 1984) and emerges as a consequence of growing awareness of the difficulties of taking the man-machine analogy proposed by information-processing theory too literally. As Bowen (1967) notes

'... we cannot be successful in utilising the resources of man in a system until we accept the fact that he contributes a qualitatively different form of operation in comparison to machine
elements. He operates adaptively and has the capability of managing whatever resources the system affords him to meet the challenges of the situation.' (p. 19)

A provision of increased operational flexibility beyond that provided by traditional information processing models appears to be a characteristic of most recent attempts to understand the production and control of human cognitive and motor skills (e.g. see MacKay, 1982).

Although these theoretical modifications to the basic information-processing model are obviously important, the principal factor restricting the utility of information processing theory is failure to validate the efficacy of the model by applying it to the examination of ecologically valid problems. As Neisser (1976) noted almost a decade ago

'... the study of information processing has momentum and prestige but it has not yet committed itself to any conception of human nature that could apply beyond the confines of the laboratory' (p. 6)

and this comment, unfortunately, appears equally pertinent today. Arguably much of the perceived 'real-world' failing of the information processing model lies not with the premises of the model itself but with the researcher's narrow laboratory-centred usage of the model.

The basic information-processing model, on face value at least, appears to offer a number of advantages as a framework for conceptualizing and studying skilled movement production within a wide range of 'real-world' skills. Information processing models, such as Welford's human performance model, provide firstly a valuable awareness
that skilled movement is a consequence of a number of intervening cognitive processes and not merely the consequence of involuntary muscular activity and serve furthermore to highlight the fact that this common base of processes underlies the production of a wide range of seemingly diverse skills. Secondly, the multi-component nature of these models highlights the many potential covert origins of movement error within perceptual-motor skills (see, for example Hale, 1970 or Sharp, 1973), whilst still explaining, on the other hand, how compensation can occur to prevent failure of one particular processing stage from leading to total skill breakdown (Rothstein, 1977b). Thirdly, and most importantly within the current context, models such as Welford's highlight the many potential processing avenues for individual differences in skilled performance and highlight the many potential loci for the improvement of information-processing as a direct consequence of practice (e.g. see Low, 1978).

Although the aforementioned theoretical limitations of the information-processing model are well recognized the potential practical advantages which may be gained in applying the information processing approach to the examination of 'real' skills argue strongly in favour of the tentative adoption of the model in the current setting. Consequently, in the absence of a viable alternative, Welford's (1960) human performance model will be used hereafter as a notional base upon which to examine the issues of perception in 'open' motor skills which are central to this thesis.
Despite some commonality in the nature of the underlying control processes, perceptual-motor skills differ in their respective information-processing demands according to the specific requirements of the task at hand (Salmela, 1976). These differences in the information processing demands of different types of skill necessitate consideration of classification of motor tasks into categories on the basis of sound classification criteria. Although a number of taxonomies currently exist for the categorization of motor tasks on the basis of observable (output) characteristics (e.g. Farrell, 1975; Fleishman, 1967; Hallberg, 1976; Harrow, 1972; Merrill, 1972) a more meaningful classification from the motor behaviourists's perspective, although a less quantifiable one, is to consider the cognitive and information-processing requirements of the different tasks.

The distinction between 'open' and 'closed' motor skills originally developed by Poulton (1957), stated more formally by Knapp (1961b, 1963) and recently extended by Gentile (1972) and Gentile, Higgins, Miller and Rosen (1975), is one such approach based primarily upon the environmental uncertainty and relative time constraints under which the skill is performed. As information-processing demand is directly proportional to the existing uncertainty this form of motor task classification provides an accessible means of comparing different perceptual-motor skills in terms of their information processing requirements, and some procedures are now available (Alain & Salmela, 1973; Salmela & Alain, 1972) for precisely quantifying the information processing requirements of some
'real-world' skills.

Within this categorization, 'open' skills are considered to be those skills characterized by high degrees of both perceptual and response uncertainty and in turn by high degrees of time-constrained information processing within both the perceptual and decision stages of skill production (Figure 1). 'Closed' skills, on the other hand, are characterized by an absence of external time constraints and a proportionate increase in dependence on the effector processes for successful movement outcomes. The successful performer in 'open' skills, consequently, is forced to constantly keep 'in touch with the demands which come from the outside world' (Bartlett, 1947, p. 835) and select and time his motor actions on the basis of environmental cues (Adams & Xhignesse, 1960) in order to produce purposeful action. The capability of maintaining both adaptability and response consistency therefore becomes a key characteristic of the successful 'open'-skill performer (Glencross, 1979) and there is considerable research interest in determining how these usually contradictory states are achieved.

In categorizing skills on a continuum from 'open' to 'closed' (or from 'perceptual' to 'habitual' as Whiting, 1969 has done or from 'externally-paced' to 'self-paced' as Singer, 1980b has done) it should be recognized that the majority of ergonomic tasks lie towards the 'closed' end of the continuum, - this being a result of the need to reduce task difficulty and error rates, in order to enhance occupational safety. Consequently to study a perceptual-motor skill at the 'open' end of the continuum within its natural setting it is usually advantageous
to examine tasks performed within sport settings. In the section which
follows, therefore, information processing within the 'open' skills
involved in fast ball sport settings will be examined.

III: INFORMATION PROCESSING IN 'OPEN' SKILLS

Throughout contemporary sport science literature information
processing models, and most especially Welford's human performance model,
have been applied quite regularly to the analysis of a number of fast
ball sports (e.g. see Abernethy & Russell, 1983; Garnier, 1973;
Marteniuk, 1976, pp. 18-27) and the model appears to provide, if nothing
else, a useful means of conceptualizing skilled performance within these
tasks.

Within fast ball sports the perceptual mechanism of the performer is
seen to be initially responsible for the prediction of the precise
spatio-temporal co-ordinates of the arriving ball, and this prediction is
achieved through the integration of pertinent information arising from a
number of different sources (see again Figure 1). Aside from the
expectations the player brings into the situation from his past
experience, current information is also available from both ball flight
and from events preceding ball flight (e.g. the pitcher's wind-up in
baseball, the opponent's backswing in tennis). Selection of this
pertinent information from other irrelevant distracting or deceiving
environmental stimuli is seen as a critical phase in skilled performance.
The results of this perceptual analysis are then passed, in turn, to the
decision mechanism which is responsible for selecting an appropriate
response (e.g. in the case of the cricket batsman deciding what stroke, if any, is appropriate in relation to the perceived characteristics of the oncoming ball). This process of response selection is constrained by both the limitations in available processing time, and the need to maintain a satisfactory level of response selection accuracy. The constraints of accuracy are imposed by the need to select, on any given occasion, a response which is not only appropriate to the characteristics of the oncoming ball, but which is also compatible with the player's (and team's) current strategy. The plan of action decided upon by the decision mechanism then has to be organized in the effector mechanism and this response organization is generally conceived to be a time-consuming process which requires precise hierarchical, sequential and temporal specification of the necessary efferent neural commands. It is only after these commands are satisfactorily organized and the neural commands are given time to reach the selected muscle groups that the required movement response becomes a reality.

Accurate coincidence-timing performance of the type characteristic of fast ball sports therefore requires the performer to have an accurate perception of not only the velocity of the approaching ball but also an awareness of his/her own central and peripheral processing latencies. Given that fast ball sports are obviously severely time-constrained a point of considerable interest is to determine how the total time available to perform the skill is allocated among each of these information-processing components. Each of the three central processing mechanisms must conceivably share the available processing time remaining after the needs of the peripheral latencies (viz stimulus reception time,
afferent and efferent neural transmission times, movement time) are met and this time-sharing between mechanisms would appear to require a quite complex form of overriding organization and control.

Unfortunately, although the human performance model (and the information processing model in general) provides a sound basis for describing, and making predictions regarding, the mechanisms underlying performance in 'open' skills the covert nature of the hypothesized central processing mechanisms makes it difficult to either make direct estimates of the time constraints placed upon each processing mechanism or to compare skill groups on the strategies they use in sub-dividing the available processing time between the various mechanisms. In view of these limitations a need appears to exist for an operationalized form of the traditional information processing model which will allow the time constraints upon the various processing stages to be independently estimated from concurrent observable events within the 'open' skill environment. The purpose of the forthcoming sections of this chapter is therefore to develop such an operational model for the examination of information processing in 'open' skills (and in fast ball sports specifically) that will allow the time constraints imposed on the various information-processing stages to be estimated.

An Operational Model for Examining Time Constraints on Information Processing

Functions of an Operational Model

In formulating an operational model which can be applied in the
assessment of information processing constraints within 'real-world' settings it is essential that a number of criteria be met. Firstly it is essential that the component stages selected within the operational model accurately reflect the underlying control processes and are therefore based on the same sequence of information processing stages previously identified in the general model (see Figure 2). Secondly it is crucial that these same component stages be able to be subjected to experimental manipulation within ecologically valid settings (Tyldesley, 1981). Thirdly, and perhaps most importantly, it is essential that the developed model serve useful functions in the production and support of associated theoretical notions on information processing in fast ball sports, and in so doing be compatible with the existing knowledge in this area. In this respect a successful operational model should be seen to contribute to the '... construction, application, and interpretation of theory' (Lachman, 1960, p. 114). Moreover in meeting this interplay with theory a model, according to Lachman (1960), should address the following functions:

1. the representational function i.e. the model should provide modes which allow a system or concept to be accurately represented.

2. the inferential function i.e. the model should, through the rules of inference, give rise to predictions which can be tested.

3. the interpretational function i.e. the model should allow the theory, and associated corollary findings, to be interpreted.

and,

4. the pictorial function i.e. the model should facilitate visual reproduction of the theoretical prototype in terms of mental images.
Figure 3: An operational model for the examination of the temporal constraints upon information processing in fast ball sports. For the derivation of the different component times refer to the text.
These criteria will be used here to both direct the development of the operational model and then, in turn, to assess the model's adequacy.

1. **Representational and Pictorial Functions**

(a) **Components of an Operational Model**

Figure 3 presents an operational model for the examination of the time constraints upon information processing in fast ball sports, which is based upon the selection of three temporal component stages (two covert and one overt stage) and the equation of these temporal components to observable environmental events. Within this model the total time available to perform the particular fast ball skill under investigation is first determined (TT) and then this time is selectively partitioned into viewing time (VT), latency time (LT) and movement (MT) components. Each of these component times is seen to be associated with one or more underlying information processing stages although the strict serial independence of each of these processing stages (Miller, 1983; Sanders, 1980) has yet to be demonstrated.

Viewing time, within this approach, is considered to be the time taken to extract and analyze information from the perceptual display and then reach a response selection decision on the basis of this accumulated information. Viewing time therefore includes processing time allocated to stimulus detection, stimulus recognition and response selection (i.e. control processes 'housed' within the perceptual and decision mechanisms in Welford's model) and non-processing time required for receptor stimulation and afferent neural transmission. These peripheral delays
between when information becomes available in the display and when it becomes available to the central processor in an appropriate neural form appear to be in the order of 50-60 msec (Wood, 1977) and this must therefore be considered as essentially a 'dead time' within the initial part of the VT in which no central processing is possible.

Latency time is the elapsed time between the completion of response selection and the commencement of the observable movement response and, like the VT, consists of both processing time (the time required for response selection) and non-processing time (the time required for the efferent neural commands issued from the effector mechanism to reach the appropriate muscle groups and induce movement). The 'dead time' in LT attributable to efferent neural transmission time, or motor outflow time, has been shown like the input delay, to be of around 55msec (Wood, 1977) although this depends somewhat upon which motor nerves are carrying the efferent commands (see Smorto & Basmajian, 1979) and the state of spinal motor neurone preparation and pre-tuning (Kots, 1977). Movement time is then simply the duration of the overt movement response, commencing with the first observable sign of movement and terminating with contact with the arriving ball.

(b) Measurement of Component Times

The success of the operational model in assessing the time constraints imposed on each of the processing stages is obviously contingent upon the precision with which each of the proposed component times can be either measured or estimated. Both the total time available
for information processing during ball flight (TT) and MT can be measured directly, and with high degrees of precision, in the field setting using high speed cinematography, or in some cases electromyography or accelerometry (for examples see either Miller & Nelson, 1973 or Grieve, Miller, Mitchelson, Paul & Smith, 1975). The determination of the duration of the LT and VT components however cannot be made with the same precision and requires rather the use of a number of assumptions and estimations.

Latency time (i.e. the delay between when the performer decides upon what response is required and when the selected action actually commences), cannot be measured directly in the field setting and must consequently be estimated from laboratory simple reaction time (SRT) measures. Laboratory SRT is however fundamentally different from LT as it occurs as a component of reactive performance in fast ball sports (Marteniuk, 1976) and consequently the accuracy of the SRT estimate of LT is difficult to assess. In some instances SRT can be expected to overestimate the length of the LT component simply because SRT contains processes (such as afferent neural transmission, stimulus detection and response selection), and associated processing times, which belong strictly to VT rather than LT. On the other hand, if the movement that has to be produced is extremely complex the response organization requirement of LT may clearly exceed those of SRT (e.g. see Klapp, 1977; Klapp & Erwin, 1976) and consequently SRT in those cases may underestimate LT both in terms of temporal and attentional (spatial) requirements. The underlying assumption of using SRT is then that, on average, it provides a reasonable estimate of the temporal delays between
covert response selection and overt response initiation. The evidence available to test this assumption from studies of error correction suggests that although traditional SRT measures may substantially overestimate latency for some fine motor skills (e.g. Carlton, 1981, has shown visually based movement corrections in aiming movements with latencies in the order of 135 msec), for gross motor skills of the type usually encountered in fast ball sports SRT appears to provide a reasonable estimate of minimal processing time (Mcleod, 1981, 1982).

The calculation of the VT component, given the value of the three other components, is achieved through simple subtraction logic by the equation \( VT = TT - (LT + MT) \). The available VT is therefore dependent upon both the speed of the approaching ball (as a direct determinant of TT), and the performer's individual speed in terms of organizing (LT) and executing (MT) the required movement skills. It can be argued on logical grounds that the steps involved here with determining VT may be very similar to the computational steps the performer actually undergoes in order to determine at what point in time his/her response selection must be completed.

As the VT parameter effectively provides an estimate of the point in the event sequence where response selection is complete, a performer's reliance upon anticipation and advance cue sources can be potentially assessed from the magnitude and sign of the VT. A large positive VT

5. Arguably however even in these studies of minimal error correction time processes other than those constituting LT are incorporated in the response delay estimates.
Figure 4: The skill of cricket batting examined from within the framework of the operational model (from Abernethy, 1984). Data are based on a cinematographic analysis of three expert cricket batsmen.
indicates the availability of substantial ball flight cues to aid response selection whereas a negative VT indicates a total reliance upon advance (or anticipatory) sources of information (Refer again to Figure 3). As different components of the same skill may have different MTs, and consequently different VTs, it is possible for components within the same skill to have quite different reliance on advance and ball flight cues respectively. In examining the skill of cricket batting, for example, from within this operational model, (Abernethy, 1984), it becomes evident that while ball flight cues are available to guide the selection of the final downswing action of the bat, movement of the feet for the same skill must be based almost entirely upon advance sources (see Figure 4).

(c) Limitations and Assumptions in the Operational Model

The subtraction logic used here in the determination of VT, like that used by Donders (1868) in the original attempts to fractionate reaction time, is open to criticism as the seriality and independence of the component stages within the operational model have not been clearly established (Taylor, 1976). Linear models of the type proposed here assume a form of discrete information-processing, in which the underlying processes and component times are conceived to be clearly distinct in time, rather than considering the possibility of continuous forms of processing (e.g. McClelland, 1979; Miller, 1982) where the underlying processes, and hence the component times, overlap. It may well be, for example, that in some cases early response organization (a LT process) can occur prior to the completion of response selection (a VT process),
thus violating the seriality assumption. Available evidence from Miller (1983) however, indicates that if this particular processing overlap is indeed possible it represents only a minor deviation from the predictions of the discrete processing model. Obviously any model will involve some substantial simplification of the actual operating mechanics of the human performer but, in agreement with Sharp (1978), it is nevertheless important to recognize that

'... skilled performance is based on more than the simple passage of information from input to output: complex interactions take place both between and within various stages of processing.'

(p. 3)

Complete validation of the operational model proposed in Figure 3 also requires demonstration of the functional independence of the proposed component stages in applied settings (Tyldesley, 1981), rather than reliance upon previous laboratory derived data (see again Figure 2 based on Sanders, 1980).

(d) Advantages of the Operational Model

On the positive side the operational model proposed here offers a number of apparent advantages over previous attempts to model information-processing performance in fast ball sports. Three prior "models" of component times in fast ball sports have been isolated in the literature - the coincidence-anticipation model of Stadulis (1972a), and the models using choice (e.g. Glencross & Cibich, 1977) and simple (e.g. Miller & Shay, 1964) reaction time to estimate available viewing time -
Figure 5: Early models of the information processing component times in fast ball sports.
and these three models are presented in diagrammatic form in Figure 5.

Stadulis's (1972) model identifies three phases that contribute to coincidence-anticipation performance of the type encountered in fast ball sport viz the pre-release phase, the object flight phase and the response phase. The pre-release phase and object flight phase provide the information upon which the decision is made regarding what response to select and when to initiate the response for correct coincidence timing. (According to Alderson, 1972 this decision to initiate the response should be made when the object is MT + SRT from the coincidence point.) The response phase of the model includes the central nervous system latency of SRT, plus the MT component. Although Stadulis sees the role of the pre-release phase as strictly anticipatory for decision-making and the object flight phase as strictly confirmatory this is not necessarily the case. The cut-off between anticipation and confirmation will not always be at the release point (or contact point) but rather will vary according to the total time available for decision-making (as reflected in TT) and according to the individual performer's MT, LT, and decision-making strategy. The advantage of the currently proposed operational model then is that it allows the time at which response selection must be completed to be estimated and expressed relative to the release point, and does not merely default to a release (contact) point separation of the anticipatory and confirmatory phases as does the Stadulis model.

The operational model also provides a number of advantages over attempts (e.g. Glencross & Cibich, 1977) which have been made to equate the time available prior to MT commencement to a CRT situation. These
advantages primarily relate to the difficulties which arise in considering the period from stimulus onset to movement initiation in the 'real-world' setting as a classical CRT situation (see Abernethy, 1981). Firstly, it is difficult, if not impossible, to locate the true commencement of the reaction time in the 'open' skill setting and therefore it is difficult to devise an exact analogue to the event of stimulus presentation in the laboratory CRT. Specifically there is the question of when usable information first becomes available in the fast ball skill (this will undoubtably vary for different individuals, for different levels of expertise and for different perceptual strategies) and the associated problem of determining how many stimulus and response alternatives the performer is being required to choose between in the field task. Secondly, using a CRT model removes the valuable distinction, drawn by the operational model, between the time spent with response selection and the time which must be allocated to effector processes; yet it is known, from laboratory tasks at least, that response selection and response organization are separate processing stages (Clark, 1979). Thirdly, the CRT analogy treats the response selection process in fast ball sports as the mere problem of selecting one response from a number of potential response alternatives in as short a time as possible whereas, in fact, the performer may rather use all the available VT at his/her disposal to confirm an earlier response selection decision. It may be, as Meredith (1966) suggests, that skilled performers '... formulate ... strategy not by reference to some minimum time factor but by reference to the time available' and for this reason independent calculation of the available VT, as in the operational approach proposed,
may become a critical consideration.\footnote{6}

The third approach depicted in Figure 5 involves the estimation of the available VT as the time available for processing of ball flight information when the central and peripheral response latencies associated with SRT and MT are preferentially satisfied. Such an approach is evident in many of the early attempts to analyze the temporal constraints in fast ball sports (e.g. Alderson, 1972; Miller & Shay, 1964; Morris, 1980; Whiting, 1969; Williams & MacFarlane, 1975) and shares many structural similarities to the operational model currently proposed. The major advance evident in the current model is in terms of the attempt to closely match the proposed component times with the underlying processing structure (see Figure 2) and the consequent awareness provided of the potential inaccuracy associated with using SRT directly as a component time rather than using SRT as an unstable and potentially biased estimate of one of the component times. The bias arising from the use of SRT to measure time constraint is generally, as has been noted previously, in the direction of over-estimating the temporal constraints imposed on the player in fast ball sports. As Hubbard and Seng (1954) noted in their classical work with baseball batters

'... estimates based on reaction time of when the batter must make his decision to start the processes which will result in the swing, place the point too far back in terms of ball flight'

(p. 42)

\footnote{6. For an example of the important role the available time plays in the response selection process in 'real-world' tasks see Drury (1975).}

For consideration of how the length of the VT may be modulated, especially in terms of either satisficing or optimizing strategies see Pitz (1969) or Mills, Meltzer and Clark (1977).
and an awareness of this potential shortfall in using SRT has not been apparent in many previous applications of this model.

The operational model proposed in Figure 3 therefore appears to offer a number of advantages over existing models of fast ball sports performance, especially in terms of the attention it gives to the necessity of maintaining a close link between selected component times and what is known of the underlying control processes. Additionally the model offers an advantage in terms of providing a VT estimate whose directional sign indicates the respective potential availability (and non-availability) of ball flight information to guide response selection and provides an approach which can be applied with equal ease in both laboratory (e.g. see Abernethy & Russell, 1984) and field (Abernethy, 1984; Howarth, Walsh, Abernethy & Snyder, 1984) settings. The facility to maintain the highest degree of ecological validity by making a totally non-invasive collection of data from subjects performing 'real' skills in an intact environment is obviously a crucial one in terms of the perceived 'real world' failings of the traditional information-processing approach (Neisser, 1967).

To date then, the operational model has been advanced in a primarily pictorial and representational form to provide a conceptual base of how the time constraints in fast ball sports might be considered. In keeping with Lachman's (1960) notions regarding models it should be recognized that this representation of the temporal constraints in fast ball sports may be applied even though these component times may not exist in a real sense or be the organization that the performer utilizes (or is cognizant
Figure 6: Predictions regarding task performance derived from manipulation of the component times within the operational model.
of) in skill production. Further examination of the efficacy of the operational model requires the higher order (interpretational and inferential) functions of the model to be examined.

2. Inferential and Interpretational Functions

Inferential and interpretational functions of the operational model extend to the issue of making predictions and interpreting existing data and literature. Although the model proposed is a multi-component one (and it is in all probability the combined effect of the components rather than any individual component which ultimately determines performance) a number of predictions can still be advanced regarding the use of the individual component times within the operational model and their relation to skilled fast ball sport performance. In the section which follows the efficacy of the operational model will be further assessed by examining the compatibility between predictions generated from the model and the extant data available on fast ball sport performance. The predictions to be assessed are:

(1) Increased total time available (TT) will produce improved task performance.

(2) Increased VT will produce improved task performance (under conditions of constant LT and MT).

(3) Decreased MT will produce improved task performance (under conditions of constant LT).

(4) Decreased LT will produce improved task performance (under conditions of constant MT).

The basis of these predictions is presented schematically in Figure 6.
(a) Prediction 1: The Effect of Total Available Time Upon Task Performance

When temporal stress is added to a task there is generally a proportionate increase in the task difficulty (Billing, 1980) and a consequent decrease in task performance. In fast ball sports the addition of temporal stress can be predicted to have non-uniform effects on the various component times of the operational model (see Figure 6). As the LT and to a lesser extent the MT components are subject to 'floor' effects (see Schmidt, 1975, pp 33-34) and cannot be shortened below certain minimal response times which are 'hard-wired' into the central and peripheral nervous systems, decreased TT is usually translated directly into a decreased VT. For this reason experimental support for this first prediction can be assessed directly from the evidence pertaining to the next prediction i.e. that decreasing the VT will directly impede task performance.

(b) Prediction 2: The Effect Of Manipulated VT upon Task Performance

By referring to Figure 3 or Figure 6 it becomes apparent that if the duration of the LT and MT components remains constant and the overall temporal stress of the skill is reduced (thereby increasing TT), then the VT will be increased and the perceptual and decision processes will become less time constrained. An increased VT would be therefore predicted to improve task performance because the reduced time constraints would afford the performer more opportunity to pick up relevant anticipatory or confirmatory cues through which decision-making uncertainty could be resolved.

Attempts to determine the influence of VT duration upon 'open' skill
Figure 7: Basic paradigm for the examination of VT manipulations upon ball catching skills (from Whiting & Sharp, 1973). Within this paradigm DP is the dark period prior to room illumination (VP). OP and LP are occluded periods of ball flight preceding ball-hand contact with the latter being an assumed constant period equivalent to CNS latency plus movement time.
performance have been directed primarily towards catching skills performed under somewhat artificial laboratory conditions. Constant object flight times (TT) are generally provided and the duration of observable flight prior to the initiation of the catching response is systematically varied in order to examine effects on catching performance. This variation is usually achieved through the selective illumination or occlusion of either the ball alone or the entire experimental room. The typical paradigm used in these catching studies (see Figure 7) provides for the independent manipulation of either the period of stimulus visibility (the viewing period) or the period of stimulus occlusion (the occluded period). A constant latency period is also usually included in an attempt to control for the inherent response latencies subsequent to response selection and this period is typically estimated from the sum of the individual subject's SRT and MT. Although the assumption of this latency period as a 'dead' time in terms of providing information that can be of use in the production and control of the catching response now appears a tenuous one in view of recent evidence on the time course of the correction of response execution errors (e.g., see Carlton, 1981; Higgins & Angel, 1970; Schmidt, 1976) and although the catching paradigm can be criticized on a number of grounds of ecological validity (Davids, 1982), the basic paradigm does provide an excellent basis upon which to examine the second prediction of the operational model.

Early investigations using this paradigm maintained not only a constant latency period but also failed to manipulate the duration of
the occluded period (Whiting, 1978). From the not inconsiderable studies which have manipulated the viewing period only (MacGillivray, 1979, 1980; Molstad, 1974; Nessler, 1973; Whiting, 1968; Whiting, Alderson & Sanderson, 1973; Whiting, Gill & Stephenson, 1970) the consistent conclusion has been reached that increasing the VT over quite a considerable range of times results in concomitant catching performance increments. Only when VTs are increased beyond about 500 msec do plateaus in catching performance become evident (Alderson, 1974). Although these studies collectively failed to confirm the existence of any clear cut 'critical period' for the extraction of ball flight information the overall findings are highly compatible with predictions that can be generated from the operational model.

Subsequent research by Sharp and Whiting (Sharp, 1975, 1976, 1978; Sharp, Farrally, Kingston, Laidler & Saunders, 1974; Sharp & Whiting, 1974, 1975; Whiting & Sharp, 1974) which manipulated not only the viewing period but also the occluded period has resulted in substantial re-interpretation of the earlier findings. When the occluded period is also systematically varied the experimental design becomes analogous to dividing the VT stage of the operational model into two components - an initial component for stimulus detection and recognition (as measured by the viewing period) and a subsequent component for response selection (as measured by the occluded period). The results of this comprehensive

7. Although the division of the VT component of the operational model into perceptual and decision components may be desirable theoretically in terms of drawing parallels to the feature detection - feature classification distinctions which are made in many models of visual perception and visual search (e.g. see Hoffman, 1978; Swennssson, 1980), the temporal distinction of these components is extremely difficult to attain experimentally.
series of studies suggest that performance is dependent on the summative effect of these two periods with either increasing the time available for either individual component (within certain ranges) or increasing the total VT available by increasing the sum of the two components, inevitably resulting in improved catching performance (Whiting, 1978). Therefore, despite the complexity introduced by selective manipulation of the VT, the results obtained are still unequivocably compatible with the prediction of the operational model. As the apparent displacement of the ball in relation to the catcher increases as an exponential function of the VT (Hubbard, 1955), and as consequently the specificity of the available ball flight information increases with extended VT, this relationship between extended ball flight viewing and response accuracy is hardly surprising.

More powerful evidence to support prediction 2 comes from evidence demonstrating improvements in task performance when the availability of advance information rather than object flight information is manipulated. Studies (e.g. Isaacs & Finch, 1983; Jones & Miles, 1978; Salmela & Fiorito, 1979; Soullère & Salmela, 1982) presenting subjects with variable extents of advance information through the use of sport-specific film sequences have also obtained improved prediction accuracy when either the amount of available pre-flight information is increased or limited ball flight information is made available to supplement the advance cues. This relationship between VT and response accuracy is retained even when subjects are required to terminate their own VTs (within realistic time-constraints) rather than having the VT duration manipulated externally by the experimenter (Abernethy & Russell, 1984) or
when the length of the VTs is allowed to vary naturally within the field setting (e.g. see Ripoll et. al's. 1982 data on basketball shooting). Similarly a powerful effect of VT upon performance has also been demonstrated in laboratory verbal-visual tasks (e.g. Goldblatt and Eacker, 1977) and in a number of ergonomic applications (e.g. see McLean & Hoffman, 1983; Senders, Kristofferson, Leivison, Dietrich & Ward, 1967) indicating the robustness of this particular effect.

The support for the second prediction of the operational model is therefore quite compelling and suggests that, apparently irrespective of the means by which VT is manipulated or the nature of the dependent measure selected, increasing the VT makes possible an improvement in 'open' skill, and especially fast ball sport, performance. Logically the support for this prediction means that the first prediction from the operational model regarding TT must also be supported in principle with the expectation that any changes in TT which result in increased VT (with no alterations in either LT or MT) will produce comparable performance improvements. Alterations in fast ball sport performance as a consequence of changes in object velocity (e.g. the soccer goal-keeper fielding a firmly struck kick as opposed to a slow kick) or the distance over which the object must travel (e.g. close volleying as opposed to baseline rallies in tennis) can then be easily comprehended within the construction of the operational model.

Predictions 3 and 4 are essentially corollaries of this initial prediction regarding the VT-task performance relationship. These two predictions examine separate means by which the amount of available VT
can be increased (prediction 3 through reducing LT; prediction 4 through reducing MT) with the consequent intention of improving task performance. In both cases the predictions of shorter LTs and shorter MTs, enhancing task performance (through increasing VT) can be examined via analysis of the data available on SRT and MT differences between expert and novice fast ball sport performers.

(c) Prediction 3: The Effect of Manipulated LT Upon Task Performance

Given the apparent importance of an extended VT in facilitating 'open' skill performance, and given that a reduction in LT is one of the available means of extending the VT duration, the prediction can also be advanced from the operational model that reduced LT should provide an avenue for improved task performance (see Figure 6). However as LT is largely composed of 'hard-wired' components which are subject to minimal within-subject variability (Wood, 1977, 1981) LT cannot be manipulated experimentally in the same manner as VT but must rather be examined through an individual differences approach. For this reason the expectation can be advanced that expert performers (i.e. performers with high task proficiency) should, on average, have shorter LTs than novice performers (i.e. performers with low task proficiency). This prediction cannot however be examined directly (in the absence of a direct measure of LT) but must be translated into the somewhat weaker working hypothesis that the SRT of expert fast ball sport performers will be shorter than that of the novice. The logic behind this prediction of below-average SRTs for expert fast ball sport performers is the expectation that
... the player with the faster reaction time can if he wishes let the ball travel further before initiating an action and theoretically at least he can use the additional time to monitor the other aspects of the display ... The player with the faster reaction time may if he wishes wait for later deviations in the flight of the ball and thus react more adaptively.  
(Whiting, 1969, p. 42)

Studies examining the relationship between SRT and fast ball sport performance are abundant and vary substantially in terms of the subject group examined, the task used, the analysis procedures selected and the findings and interpretations drawn (see Appendix A-1). Although a large number of early studies directly supported the concept of a linear relationship between SRT and skill level (e.g. Beise & Peaseley, 1937; Griffith, 1928; Knapp, 1961a; Olsen, 1956; Sigerseth & York, 1954; Westerland & Tuttle, 1931) and between SRT and the demands of different sport tasks (e.g. Bhanot & Sidhu, 1980a; Burke, 1972; Cureton, 1951; Wilkinson, 1958; Zimmerman & Lane, 1976) the evidence in more recent studies (e.g. Hellweg, 1973; Min, 1967; Sanderson & Holton, 1980; Yandell & Spirduso, 1981) is far less clear-cut. Contemporary reviews of the SRT-skill level relationship (e.g. Hutt, 1972; Marteniuk, 1974; Starkes & Deakin, 1984) now indicate only a mild relationship between SRT and fast ball sport performance although in the absence of any negative findings the failure to show a consistent relationship in many cases may be merely the consequence of poor subject selection, experimental design, statistical treatment etc. (See Appendix A-1 for a summary of the available studies and the methodological problems). When ecologically valid stimuli are used skill group distinctions on the basis of SRT are

The existing data therefore, although not always supportive of a strong relationship between SRT and performance level, can be seen to be rarely in contradiction to the prediction of a shortened LT facilitating performance. Negative findings, i.e. findings where the SRTs of the novices are significantly shorter than experts, are not apparent in any of the reported studies. In those studies which fail to observe a direct SRT effect upon performance problems associated with (a) poor experimental design etc. (see Appendix A-1), (b) the imperfect assessment of LT effects from SRT and (c) the possible compensatory effects of other variables (e.g. decreased MT), can be used to account for the absence of significant effects without contradicting the LT prediction (prediction 3).

(d) Prediction 4: The Effect of Manipulated MT Upon Task Performance

A number of authors in considering performance in fast ball sports (e.g. Hay, 1973, p. 211; Schmidt, 1975, p. 139-141; Stallings, 1982, p. 163-164) have suggested that by reducing the MT involved in sport skills more time should become available to perceptually analyze oncoming ball flight and to select an appropriate response. The extension of VT, through shortened MT, is therefore predicted, as it is with the operational model framework (Figure 6), to facilitate fast ball sport performance. Although the MT component of fast ball sports can be experimentally manipulated in a fairly crude manner, the validity of this
prediction, like the previous prediction, can best be examined in natural settings by comparing the MTs of expert and novice performers.

When studies comparing the MTs of expert and novice fast ball sport performers are evaluated (for a summary of the existing studies see Appendix A-3) the available evidence is generally in line with the prediction of shorter MTs for experts (e.g. Breen, 1967; Burke, 1972; Keller, 1942; Konzag, 1983; Nagykaldi, 1972; Pierson, 1956) although there are obvious exceptions where MT is not identified as an important discriminatory variable (Yandell and Spirduso, 1981) and other variables, such as SRT, are implied to be more important (e.g. Olson, 1975). As was the case with the SRT studies (Appendix A-1), the clearest demonstration of lower MTs for experts occurs when MT recordings are made in the actual performance setting and when the distinction of groups on the basis of proficiency level is substantial (i.e. when truly novice control groups are incorporated into the experimental design).

The observation of generally shorter MTs for expert performers does not, however, necessarily indicate, as many previous authors have implicated (e.g. Schmidt, 1969; Schmidt, 1975, p. 140-141), that attempting to reduce the MT to create more VT (and to improve response accuracy) is a desirable strategy for any performer. There are a number of quite complex trade-offs which need to be considered in assessing the value of a decreased MT – the most important of which relates to the need for the performer to maintain movement consistency.

Although the highly skilled performer cannot always be characterized
by a shorter than average MT he/she can be typified, almost without exception, by the production of a movement response which is highly consistent in both its temporal and spatial characteristics. Movement times of low temporal variability have been observed for expert performers in a wide range of both laboratory (e.g. Bober, Rutkowska-Kucharska & Kulig, 1979; Grose, 1967, 1969; Schmidt, 1968a; Spaeth-Arnold, 1976) and field (e.g. Abernethy, 1984; Hubbard & Seng, 1954) tasks, and the value of this consistency is evident both in terms of making the timing of coincident movement responses easier and in terms of freeing some of the performer's limited attentional capacity. Having an awareness of one's own MT in 'open' skill situations effectively removes one degree of freedom from the problem of coincidence timing (Rothstein, 1977b; Tyldesley & Whiting, 1975; Tyldesley, 1980) and allows the expert performer to correctly 'time' his response merely through varying the time in object flight at which the movement response is initiated. As Whiting (1975) has noted

\[
\text{Were the expert not able to judge, from past experience, the critical timespan of his ballistic actions, then any accuracy in the initiation point of the executive motor program would be functionless. (p. 43-44)}
\]

It is undoubtedly this awareness of MT and, in view of the low variability of the expert's SRTs (Knapp, 1961), possibly also LT, which provides the potential for the coincidence-timing process to be controlled by a single visual variable, such as 'time-to-contact information' (Lee, 1980; Soloman, Carello & Turvey, 1984; Turvey & Kugler, 1984).
Consistency of the movement response is usually one of the first aspects of a given perceptual-motor skill which can be seen to become automated (Hoffman, 1974; Marteniuk, 1976) and this consistency results quite rapidly in the production of sensory feedback which is largely predictable and hence redundant. Recognition of this afferent redundancy facilitates a shift in the performer's mode of motor control from a feedback-dependent closed-loop mode to an open-loop mode in which the efferent neural commands are essentially pre-programmed (Moxley & Moxley, 1977; Pew, 1966; Schmidt & McCabe, 1976; Shea, 1980). Open-loop control reduces the attention demand of the response production process (Glencross, 1978b; Wrisberg & Shea, 1978) effectively freeing additional attention which may then be potentially allocated to concurrent perceptual or decision processes. Most importantly this additional attention which may be allocated to the perceptual and decision processes by the experienced performer can occur without any associated changes in any of the component times underlying performance as the temporal and spatial limitations in information processing are essentially distinct (Glencross, 1980b; Keele, 1972). It would appear, therefore, that although in the early stages of learning a reduction in MT may be advantageous in fast ball sports, for the most part MT consistency appears to be the single most important response consideration.

There are also a number of other motor control considerations which make the reduction of MT a strategy of questionable benefit. Aside from the obvious benefit of providing more current, and hence more specific, VT information shorter MTs are possibly also advantageous in terms of allowing more reflexive modifications of movement to take place (e.g.
Williams & Sullivan, 1978), and in terms of allowing for improved timing accuracy and consistency (Newell, 1980; Schmidt, Zelaznik, Hawkins, Frank & Quinn, 1979). On the negative side reduced MT may result in the loss of visual information capable of controlling the movement during its actual execution (Fitch & Turvey, 1979) and the possible transition to open-loop control, although reducing ongoing attention demands, may carry with it increased pre-programming demands (Williams, 1979) - demands which may divert attention away from other important concurrent processes. Some of this potential difficulty with pre-programming demands can however be overcome, at least to a certain extent, by pre-cuing some of the required movement parameters (Kerr, 1978; Klapp, 1977). Clearly then there are some doubts about the overall benefit of decreasing MT beyond certain levels but nevertheless there is nothing in the available data which is inconsistent with the predictions of the operational model or which cannot be interpreted meaningfully within the framework provided by the operational model.

In assessing both the SRT (prediction 3) and MT (prediction 4) literature it is important to remember that within the operational model there are three potential component times which may vary and it is most probably the summative effects of the various components rather than the individual effects of any single component which exerts the most powerful influence upon performance (Gabert & Castle, 1979). Although SRT and MT are unrelated in laboratory settings (Henry, 1952, 1961; Hodgkins, 1962; Slater-Hammel, 1952) they become inter-dependent in applied settings in the determination of VT, and consequently the potential exists to
compensate for slow processing in one component time with excessively fast processing in another component. As Clarke (1971) has stated in relation to primarily anthropometric and physiological parameters:

Although successful athletes generally have common characteristics, the pattern of these characteristics varies from athlete to athlete; where a successful athlete is low in such a trait, he compensates by strength in another. (p. 255)

However, because temporal stress increases at the higher levels of competition in fast ball sports, extremely slow processing in any one of the components becomes increasingly difficult to compensate for at high levels of performance and becomes an infrequent characteristic of the expert performer. Indeed as Poulton (1965) has noted in surveying the SRT literature:

The only certain generalisation is that the man with the long reaction time will not be good at fast ball games. But to be good demands more than simply a short reaction time. (p. 39)

To date therefore the literature reviewed on both independent and inter-dependent manipulations of the proposed VT, LT and MT components of fast ball sport performance is totally explicable in terms of the operational model. To this end, in dealing with existing literature at least, the model has been shown to be useful in fulfilling both inferential functions (e.g. the model's predictions regarding VT are supported by the extant literature) and interpretational functions (e.g. the model allows the somewhat equivocal SRT-skill level relationship to be interpreted). In view of its previously demonstrated capability to also serve pictorial and representational functions the operational model...
will be tentatively adopted\(^8\) here as a framework upon which to objectively study information processing within fast ball sports. In the section which follows the model will be applied to one particular fast ball sport to objectively demonstrate the extent of the time constraints which impinge upon information processing in this category of perceptual-motor skills.

**IV: TEMPORAL CONSTRAINTS UPON INFORMATION PROCESSING IN FAST BALL SPORTS**

A number of estimates of the time constraints upon information processing in fast ball sports using the measurement premises of the operational model already exist in the literature. These are estimates based on the assumption that the maximal time available for the performer to view object flight (VT) can be estimated by subtracting the combined sum of the performer's SRT and MT, from the flight time (TT) of the ball or its equivalent. Typical of these estimates are the time line estimates for selected skills involved in baseball, cricket and tennis provided by Glencross and Cibich (1977) - an example of which is redrawn in Figure 8 to adhere to the same form as that provided in the operational model. In the skill of cricket batting, for example, when facing a fast bowler releasing the ball at 90 miles/hour these authors suggest, and logically so, that

\(^8\) The model's adoption can only be tentative because the seriality and additivity assumptions of the model have not yet been adequately tested within an applied setting.
Figure 8: Linear estimate of the temporal constraints evident within the skill of cricket batting. Component time estimates are based upon a release velocity of 90 mph over an effective bowling distance of 58 feet and a MT of 250 msec as provided by Glencross and Cibich (1977).
If the ball takes 439 msec. and movement time is 250 msec. then the batsman has a maximum of 189 msec. to react to the ball. Clearly the batsman must anticipate the direction and position of the ball very early in flight, and also the batsman would have to initiate part of the stroke (the backswing and feet position) prior to delivery. (Glencross & Cibich, 1977, p. 73)

Adding a 200 msec. estimate of LT9 to the figures provided by Glencross and Cibich (see Figure 8) clearly illustrates the severity of the time constraints which exist upon VT and strongly implicates the importance of early advance sources of information in guiding decision-making under these conditions of high temporal stress. This conclusion regarding the importance of advance cues in decision-making is supported by other temporal (Hutt, 1972; Whiting, 1969, p. 43; Williams, 1973) and experimental (Abernethy, 1984) analyses of this particular skill, and appears to remain true even when the release velocity of the bowler is substantially less than that used in the above example (see Abernethy, 1981).

Despite some inaccuracy in the estimation of VT arising from either (a) estimating MT from laboratory measures rather than field measures (e.g. compare the laboratory estimates of feet movement in cricket used by Whiting, 1969 from the studies of Eastwood, Entwhistle, Gill and Stephenson, 1968 with the field measurements in Abernethy, 1984), (b) estimating TT from object release velocities rather than actual transit

9. 200 msec. is a representative value frequently reported for visual SRT (Woodworth & Schlosberg, 1954, p. 8-42) and is a time constant arbitrarily selected to represent LT in some field studies using the operational model (e.g. see Howarth, Walsh, Snyder & Abernethy, 1984).
times (thereby failing to consider slowing of the ball in flight due to either air resistance or, where applicable, contact with the playing surface e.g. see Penrose, Foster & Blanksby, 1976) or (c) failure to consider the inaccuracy arising out of the use of SRT to estimate LT, a substantial list of research papers, evaluating other fast ball sports, is now available to support these conclusions regarding the temporal constraints upon VT. Estimation of the temporal constraints in tennis (Morris, 1980), baseball (Hubbard, 1955; Slater-Hammel & Stumpner, 1950), softball (Miller & Shay, 1964), and volleyball (Toyoda & Furusawa, 1982), and goal-keeping in ice hockey (Drouin & Larivière 1974; Drouin and Salmela, 1975) and soccer (Geshev, 1974; Keller and Hennemann, 1979) all provide sound arguments for the importance of anticipation, and advance cue usage, in fast ball sports generally. These theoretically derived conclusions regarding the importance of anticipation in fast ball sports are also clearly supported by evidence available from field studies in which the onset of initial movement, recorded either cinematographically (Howarth et. al., 1984; Abernethy, 1984; see Figure 4) or through force transducers and electromyography (Nakayama & Kawase, 1984), has been shown to occur, in many instances, prior to the availability of ball flight information.

Overall, therefore, the analysis of the temporal constraints in a wide range of fast ball sports indicates that the time available to perceptually analyze the display and to then reach an appropriate response selection decision (i.e. the VT) may be, in many cases, extremely limited. Quite clearly if the performer is to be successful,
This limited available VT must be used extremely efficiently and, in view of the inferential function of the operational model, this gives rise to a fifth prediction which is the central concern of this thesis. Specifically this prediction (prediction 5) states that:

(5) Under conditions of constant VT, improved use of the available VT for information extraction will produce improved task performance.

The efficacy of this prediction in terms of demonstrating proficiency-related differences in the use of the available VT will be considered in the next chapter.

V: SUMMARY

This chapter has considered the application of information processing models to the analysis of the perceptual-motor skills involved in fast ball sports. It has been noted initially that there has been a general failure of the traditional information processing model to address 'real-world' issues in motor behaviour and this was seen, in the case of 'open' skills, to be especially unfortunate in view of the potential value that analyses of fast ball sports from an information processing perspective could provide. Consequently, in order to examine information processing within fast ball sports, an operational model was advanced in which the total time available to perform a given fast ball skill was partitioned into three temporal components - a VT component, which accounted for the time taken to perceptually analyze the existing display and select an appropriate form of action, a LT component which accounted for the time taken in organizing the selected actions and
passing the necessary neural commands to the muscles, and a MT component which was equal to the duration of the actual movement response. An attempt was made to equate the model’s structural components to previously identified control processes (and processing stages) in perceptual-motor skills and then the efficacy of the model was examined by testing the capability of predictions derived from the model to explain relevant existing sport science literature.

Considerable evidence was found to support the notion that selectively increasing the VT through either increasing TT (prediction 1), decreasing LT (prediction 3) or decreasing MT (prediction 4) would enhance 'open' skill performance although the overall effect of manipulating these independent component times upon performance was found to be subordinate to the summative effect of all three components. By adopting the premises of the developed model, on the basis of this evidence, VT in a number of fast ball sports was then shown to be extremely limited to the point of necessitating, in many cases, the performer's total reliance upon advance cues for decision-making. Examination of means of improving the efficiency of VT usage, and of potential proficiency-related differences in VT usage, were seen as the next important directions for this thesis.
It was noted in the previous chapter that the opportunity to increase the available VT through decreasing MT and/or decreasing LT becomes somewhat limited after the initial stages of skill acquisition as both MT and LT come quite rapidly to approach minimal levels. Consequently after the motor component of any fast ball sport becomes consistent most subsequent increments in task performance must be attributed to a more efficient use of the available VT rather than to increments in the duration of VT per se. This therefore directs research interest toward the perceptual and decision-making processes occurring within the VT.

Clearly two important issues which need to be resolved in relation to information processing within the VT are the determination of (1) how the total available environmental information is reduced to meaningful quantities by the performer and (2) how only the pertinent (or regulatory; Gentile, 1972) information is selectively processed whilst irrelevant or distracting information is disregarded. Both these related issues require consideration of the process of selective attention and it is the consideration of this process, and the mediating effects of experience and task proficiency, which forms the principal focus of this chapter.
I: THE SELECTIVE ATTENTION PROCESS

Functions of Selective Attention

It has long been recognised that very real limits exist in the capacity of the human performer to process incoming information (e.g. see James, 1890 or Boring, 1950). As input information from a wide range of both internal and external sources constantly impinges upon the performer and as this collective input would, at any single instant, clearly exceed the limited processing capacity of the human performer, it becomes necessary for the human performer to develop effective means of attending to only the most pertinent of information. Selective attention can therefore be considered as the covert process which is responsible for filtering the input information so only the most relevant information gets processed and as that process which ensures that the available processing capacity is allocated in a proportion appropriate to the perceived importance of the various input signals. Clearly, understanding selective attention requires some conception of both what properties of the input signals are used as a basis for selection and, in turn, of how the processing capacity is allocated amongst competing input signals (Reynolds & Flagg, 1977, p.17).

Models of Selective Attention

Concerted attempts to understand the functioning of selective attention, and attention in general, have abounded in the experimental

10. It has been estimated that under normal conditions approximately 30,000 bits of information may impinge upon the human performer every second (Estes, 1975-76).
psycho

cology literature for the last four decades (e.g. for a review of
models of attention by decades see Broadbent, 1982). Not surprisingly
with this amount of research "attention" a large number of models have
emerged varying primarily in terms of the time, or information-processing
stage, at which selection is envisaged to occur and, in turn, in the
perceived availability of parallel and serial processing at various
stages throughout the selection process (e.g. see Barber & Legge, 1976,
pp. 76-89; Keele, 1973, pp. 147-151; Kerr, 1982, pp. 161-169; Magill,
1980, pp. 118-121; Reynolds & Flagg, 1977, pp. 18-26; Schmidt, 1982a, pp.
134-136; Stelmach & Hughes, 1983; Wickens, 1984).

Most early models of attention grew out of attempts to explain the
so-called 'cocktail party phenomenon' described in the dichotic listening
studies of Cherry (1953) and adopted an approach which essentially
considered attention as a fixed-capacity commodity (see Schmidt, 1982, p.
134). Most noticeably Broadbent (1958) proposed that selective attention
took place via an early filter mechanism which selected input for central
processing on the basis of some physical characteristics of the incoming
signals, assessed whilst the signals were briefly held in representational forms in short-term memory. Non-attended information,
although stored temporarily in short term memory, was considered to be
subject to rapid decay and was predicted to be lost unless switching of
sensory channels took place. The fact that relevant information
presented to the non-attended channel in dichotic listening tasks could
reach the level of consciousness (Moray, 1970), and therefore must be
processed through central channels, led to the demise of the Broadbent
model in its original state. Treisman's Filter-Attenuation theory which
Figure 9: A pertinence-based model of selective attention (after Norman, 1968, 1969). This figure is based upon one presented by Martenluk (1976, p. 80).
followed (Treisman, 1960) provided modifications to Broadbent's model in terms of conceiving of the selective attention filter as having a much later locus in the information-processing sequence, with selection only occurring after a substantive series of increasingly complex signal analyses had been completed. The complexity of this model however detracted from its attractiveness as a parsimonious means of explaining a process, which in 'real-world' settings, occurs with great adaptability and rapidity.

A more attractive model of selective attention was presented by Norman (1968, 1969), based in part upon earlier work on signal analysis by Deutsch and Deutsch (1963). Norman proposed that signal pertinence, derived from the performer's past experience and contextual knowledge, was the basis for enhanced processing of any particular incoming signal and that short term memory rather than an earlier filter was the effective locus for the selective attention process. Within this model signals arriving at the sensory receptors were considered to be initially analyzed for features and were then considered to have automatic access to their stored representations in memory — representations that were pre-activated in accordance to their priority or predicted pertinence (see Figure 9). Selection of signals for further attentive processing was considered to be the outcome of the overall memory activation levels arising from the joint inputs from the current sensory analysis and the expectancies arising from prior, remembered experience. The selection process in this way was then conceived of as being both 'data driven' (by
the current input) and 'conceptually driven' (by the experiential input) (Norman, 1976, p. 40-41). Input signals most likely to be selected for continued processing within this framework are therefore those which are both preconceived of as being of high pertinence and which are also revealed by the sensory analysis to be physically present.

Despite the innovations provided by the Norman 'pertinence' model, especially in terms of explaining the role that experience plays in the selective attention process (Magill, 1980 pp. 119-121; Marteniuk, 1976 pp. 80-84), this model still provided an essentially fixed-capacity viewpoint of attention with strong structural constraints being proposed. More recent attempts to model the process of attention have however viewed attention not within the context of a fixed structure with rigid processing bottlenecks (Glencross, 1978b, pp. 72-96; Schmidt, 1982a, pp. 134-137) but rather as a limited general capacity pool in which the allocation of attention between processes is seen as relatively flexible (Kahneman, 1973; Moray, 1967; Wessells, 1982 pp. 85-96). The structural bottlenecks, coinciding with the transition from serial to parallel processing, which are evident in the early undifferentiated fixed-capacity models of attention are considered within this context to be merely the result of specific task configurations and adopted subject strategies (Glencross, 1978a). These global flexible models of attention have, in turn, given way to multiple resource theories of attention (e.g. see Navon & Gopher, 1979; Wickens 1980) which now conceive of attention more accurately as a collection of sub-capacities or resource pools, each with their own particular processing limitations and responsibilities. (For detailed descriptions of the evidence supporting these contemporary
multiple resource models see Allport (1980), Stelmach and Larish (1980), Stelmach and Hughes (1983) or Gopher and Sanders (1984)).

The concept of attention seems subject to such continued conjecture and rapid focal change that one could be excused for being skeptical as to whether the current thinking is indeed representative of the attentive process in reality and indeed whether it will be representative of the paradigmatic approach to the study of attention a few years hence. In view of the changing orientations to what constitutes 'attention' and how it may be represented (Stelmach & Hughes, 1983) adoption of any theory of selective attention as a framework for the study of applied problems will be fraught with some theoretical uncertainty. However as the scope of this thesis does not extend to examining theoretical notions of attention in detail one particular model (Norman's (1968) 'pertinence' model) will be adopted here to provide at least a framework within which to consider selective attention in fast ball sports. Although this model may not provide a flawless theoretical explanation of attention\(^{11}\) the pertinence model is advantageous in terms of:

1. being directed at selective attention rather than attention in a more global context,
2. being somewhat unaffected in its basic premises by the conceptual debate as to whether total processing-

\(^{11}\) For example for more recent viewpoints on attention by Norman himself see Norman and Shallice (1985)
space is of fixed or flexible format or whether selection proceeds in a serial or parallel manner and (3) most importantly, providing a logical framework in which to examine the role of experience upon selective attention - a concern which is central to this thesis.

Detailed consideration of the applications of the 'pertinence' model to selective attention within fast ball sports is made in the sections which follow, with particular emphasis given to the mediating effects of the player's level of proficiency and experience.

Selective Attention in Fast Ball Sports

Although originally developed on the basis of studies using auditory signal inputs\(^\text{12}\), Norman's model provides a feasible account of how visual information from a number of concurrent sources plays a role in the determination of the perceptual strategy adopted by the fast-ball sport player. Disregarding the substantial non-visual input which continuously bombards the performer's receptor systems, dominant visual information is available to the player from current sources, in the form of both advance and object flight cues, and from memory sources, in the form of images and expectancies stored from prior experience. The performer's expectancies and awareness of contextual information arising from prior

\(^{12}\) Validation of the majority of theories and models of selective attention for visual signal input has been impeded by the absence of a visual analogue to the dichotic listening paradigm e.g. see Irwin (1979) or Avolio, Alexander, Barrett and Sterns (1981) for recent attempts to develop standard tests of visual selective attention.
relevant fast ball sport experiences are considered to excite representations in a memory system which also receives current environmental information via the stimulus-analyzing mechanisms (see Figure 9). The selection of information in the ball sport environment for detailed analysis and processing is considered to arise therefore as a consequence of the extent to which specific correspondence occurs between current sensory inputs and the pertinence inputs based on prior experience. Clearly this dual focus in the selective attention process, and the covert nature of the pertinence inputs especially, make simple prediction and interpretation of perceptual strategies in sport difficult. (Examples of the application of Norman's model to information processing in fast ball sports may be found in Marteniuk, 1976, pp. 80-84 or Kerr, 1982, pp. 165-169).

At least three key factors play a large part in determining the efficacy of the selective attention process in fast ball sports - the amount of information in the display, the time available to take in the required information and the ability of the player (M.G. Jones, 1972). As the information processing load and the imposed time constraints are usually high in fast ball sports errors in attentional allocation within these settings are quite prevalent (e.g. see Nideffer, 1979). Fortunately the genesis of these selective attention errors can be explained quite readily within the Norman framework. For example, the necessity to process large amounts of information in short periods of time may prevent the current sensory analysis from being a comprehensive or exhausting one and this may, in turn, result in an incomplete or inaccurate 'picture' of the current environmental status reaching the
short term memory locus. Similarly excessive time constraints, especially associated with relatively high degrees of uncertainty, may also impede the establishment in memory of appropriate pertinence information, although this problem may be conceivably relieved to some extent by bringing forward a number of relevant expectations and context-related strategies prior to entering the performance setting (Marteniuk, 1976). Inefficient or inaccurate input from either of the sensory or pertinence sources will theoretically impede the efficiency of the selective attention process.

An inter-related issue to the effect of information processing load and temporal constraints upon selective attention is that of the role of the ability or experience level of the performer in influencing the selective attention process. It is well known in many dynamic laboratory tasks such as tracking (Fuchs, 1962; Garvey & Mitnick, 1957) that with experience and learning there is an alteration in the cues used to control performance and the perceptual strategy used to extract information from the display. As selective attention is quite amenable to practice and selective attention strategies, at least for simple tasks, can be apparently learnt (e.g. Vadhan & Smothergill, 1977; Zaporozhets, 1958) there appears to be a constant search by learners for optimal selective attention strategies in terms of their respective values and costs (Wickens, 1984, pp. 263-266). Indeed skill acquisition can be considered in many ways as the optimization of this process (Girouard, 1980).

Within Norman's model improved selective attention performance, like
performance errors, has two potential origins — there may be improvements in the manner in which the available current sensory information is analyzed or there may be improvements in the assignment of pertinence arising as a consequence of the learner's expanding experiential base (see again Figure 9). The most potentially important means of selective attention improvement with experience would appear to be through enhancement of the pertinence inputs to short term memory, with experience providing not only a wider store of potentially relevant memories and context awareness but also more rapid and automatic access of this contextual information to the selective attention process (Schneider & Fisk, 1983). As Sharp (1978) notes with respect to the apparent automaticity of the selective attention of skilled fast ball sport performers:

The fact that top-level performers sometimes cannot recount and describe how it is they perform so skillfully in these situations suggests they may be operating at a "pre-attentive" level of processing having predicted the situation through contextual information and expectations derived from experience. (p. 5)

The consideration of experience and proficiency-related differences in the selective attention strategies used in fast-ball sports is of central interest in this thesis and this consideration will commence in the sections which follow by examining potential differences in the perceptual strategies of expert and novice performers as predicted from information processing notions.
II: PROFICIENCY-RELATED DIFFERENCES IN SELECTIVE ATTENTION

As skill acquisition depends on the manner in which the player processes information associated with the situation at hand (Glencross, 1978c) differences in the perceptual strategies used by experts and novices can be predicted to arise from a number of sources related to information processing. Selective attention differences between experts and novices may arise from

(1) differences in the amount of input information the two groups need to process in order to derive an accurate perception of the existing environmental conditions

(2) differences in the extent of automatic processing occurring within the selective attention process (LaBerge, 1981; Schneider & Fisk, 1983) i.e. differences in the demands placed upon attentional resources by the processing of any given amount of input information

and (3) differences in the specific cues attended to during the VT i.e. differences in the specific informational sources upon which the perceptual analysis and response selection is performed.

Proficiency-related differences in the use of perceptual strategies, such as anticipating, scanning and focusing, to reduce the quantity and to enhance the quality of the to-be-processed input information, have been
frequently suggested in reviews of information processing in motor skills (e.g. see Singer & Gerson, 1981) but the available evidence for such differences existing in 'real-world' skills is very rarely evaluated. Statements presuming differences in the selective attention strategies and capabilities of expert and novice games players are prevalent in the sports science literature (e.g. see Glencross, 1978c, pp. 101-102; Knapp, 1963, p. 160) but the empirical evidence demonstrating such differences in information processing quantity and quality in perception has been infrequently reviewed or critically assessed. It is the purpose of the following section of this review to rectify that situation.

(1) Differences in the Quantity of Information To Be Processed

Redundancy Recognition, Anticipation and Information Reduction

Because of the time constraints under which the selective attentive process must operate in fast ball sports, and the large amounts of information which must be processed in that time, any player will be at an advantage if he or she can develop effective strategies for decreasing the amount of information needed. One of the most effective means of reducing the amount of information that needs to be processed\(^\text{13}\) occurs if the performer is capable of recognizing redundancy within the perceptual display presented by his/her opponent(s). Recognition of an early cue within an invariant sequence of events provides a powerful means of decreasing the quantity of information to be processed, as all events

\(^{13}\) Other means of reducing information processing load through the a priori recognition of unequal event probabilities etc. are considered in a later section (see pp. 103-106).
subsequent to the cue become redundant and therefore, by definition, carry no uncertainty or information processing load.

Differences in the ability to recognize reliable advance cues which signal the onset of invariant sequences (i.e., differences in anticipatory ability) may exist between the expert and the novice performer in fast ball sports. It may well be, for instance, that the expert player has either an innate or acquired ability to recognize situational redundancies beyond that possessed by the lesser skilled performer, the obvious advantage of such a capability being that

In an invariant sequence of events the skilled man views all his information at it's beginning; the unskilled is waiting to receive what is, if he did but know it, redundant information. Literally, then the skilled man has more time to act ...

(Annett & Kay, 1956, pp. 114-115)

Logically therefore, the first signal in an invariant sequence assumes weight as a critical cue in perception and response selection, although clearly anticipatory strategies based on the appearance of a single critical cue will only be fully effective if the events following the initial signal can be predicted with absolute certainty. In many cases the skilled performer may, in theory, recognize not so much key individual cues preceding an invariant sequence but rather the early emergent characteristics of the "whole pattern" of action (Glencross, 1978c, p. 115). This may be used in a similar manner to single cue recognition to reduce the total information processing load and to allow critical response selection decisions to commence earlier in the event sequence. In either case this reduction of a total informational
sequence (such as the predictable sequence of events occurring in many fast ball sports) to a single critical cue or pattern of cues, termed cue abbreviation (Lawther, 1972, p. 108), can, in theory at least, provide an avenue through which skilled performance may be enhanced. An important subsequent issue is therefore whether these hypothesized differences in early cue recognition and anticipatory capability actually occur in 'real world' settings.

**Basic Laboratory Studies of Anticipation**

Although the absence of well developed anticipatory skills in young children (e.g. Kay, 1957), or in adult learners placed in novel situations (e.g. Rockwell, 1972), is frequently advanced as a basis to explain poor performance in many 'real-world' skills, much of the examination of the effects of redundancy awareness and anticipatory skill upon performance has taken place through basic laboratory studies. Within these settings a number of different forms of anticipation have been identified (Christina, 1977; Poulton, 1957), each of which is seen as playing an important role in skilled performance. It is apparently, as Kahneman (1973) suggests that

> anticipation facilitates performance in several ways: it permits response integration, and thereby effectively reduces the number of discrete choices and decisions that must be made. It also permits a smooth adjustment of effort to the difficulty of each choice and each response. (p. 192)

Much of the basic, laboratory-based research on anticipation has proceeded within the framework provided by Poulton's (1957) taxonomy of
anticipation types, developed initially for use with tracking tasks. Three types of anticipation were identified by Poulton; these being effector anticipation, which involves the anticipation of the afferent feedback associated with movement production, receptor anticipation, which involves the anticipation of stimulus characteristics under conditions where the future pathway (or "track") of the critical stimuli is physically visible and perceptual anticipation, which involves the anticipation of stimulus characteristics under conditions where the future stimulus pathway is not displayed (Dorfman & Goldstein, 1975).

Effector anticipation has already been seen to serve important functions in the timing and smoothing of response production (see Chapter 2, pp. 52) and its role in response production appears beyond question (Kay, 1970, p. 142). Receptor and perceptual anticipation, which are more akin to the kinds of anticipatory behaviours required during the VT of fast ball sports, have been examined in laboratory settings primarily through manipulations of the extent and predictability of the anticipatory information available or through variation of the amount of practice provided. (For a review see Schmidt, 1968b).

In tracking, coincidence-timing, and reaction time tasks provision of either totally or partially redundant advance information in either a physically present (receptor anticipation) or statistically implied (perceptual anticipation) form appears to facilitate task performance (Barth, 1980; Dorfman & Goldstein, 1975; Leonard, 1953; Poulton, 1964; Wilberg, 1969) and allows the search for critical display information, the essence of selective attention, to be performed more optimally (Tulga
& Sheridan, 1980). Improvements in performance over practice in these tasks have been shown to be a direct reflection of gains in the anticipatory ability of the subjects (Adams & Creamer, 1962) and these improvements appear to occur irrespective of whether the task requires a discrete (e.g. Bahrick, Noble & Fitts, 1954; Poulton, 1950) or continuous (e.g. Jeeves, 1961; Poulton, 1952) form of response or whether the advance information provided specifies temporal (e.g. Klemmer, 1956, 1957) or spatial (e.g. Leonard, 1958) parameters.

A number of attempts have been made to consider anticipation of the type elicited in fast ball sports as essentially a form of perceptual anticipation (e.g. see Alderson, Sully & Sully, 1974; Salmela & Fiorito, 1979; Schmidt, 1975, pp. 138-139; Tyldesley, 1981) but there are a number of problems and ambiguities (see Abernethy & Russell, 1982; Appendix 0; Proteau & Moisan, 1981) in applying Poulton's taxonomy in this context. In view of the need to preserve ecological validity within the testing environment (Neisser, 1976) a more appropriate approach to examining anticipatory ability in fast ball sports than that provided by the use of basic laboratory tasks would appear to be provided by experimentation using sport-specific stimuli.

**Applied Sport-Specific Studies of Anticipation**

Statements proposing greater utilization of advance cues (i.e. greater anticipatory capability) by highly skilled performers abound in texts of motor behaviour and in the sport science literature generally. Knapp (1963, p. 56), for example, has noted that
The outstanding games player seems to react to situations much sooner than the average performer. This is probably due in part to his identification of cues which appear early rather than having to wait for the later and more obvious ones.

Similarly Lawther (1972) has implicated the importance of advance cue usage in skilled performance in fast ball sports in a more global manner by observing that

If the individual has had much experience with other people in many and varied human movement patterns, he perceives the specific movement pattern of the moment even as it occurs. In baseball he recognizes the start of the batter’s attempt to bunt or of his forceful swing of the bat. In tennis he detects the overhead smash even as he sees the preliminary position of his opponent; or he detects the attempt at high lob by the arc of swing of the opponent even before the act is completed. (p. 106)

More recently Maschette (1980) has forwarded the similar contention that

As a player improves his level of performance he will need to shift his source of stimuli to earlier cues in his opponent’s motor behaviour. The shift in cue extraction will give the player more time to process information and make a decision in line with the increase in speed of other players and objects. (p. 10)

Until relatively recently however, the majority of these statements have been based on mere observation and assumption rather than upon a basis of strong empirical evidence. Fortunately within the last decade this issue of the role of anticipatory capability in skilled performance has attracted more scientific investigation from both laboratory-testing and field-testing perspectives and much of this has emerged from the seminal work of Jones in the 1970’s (Jones, 1972; Jones & Miles, 1978).
(a) Evidence from Film-Simulation (Laboratory) Studies

Although some earlier attempts exist (e.g. Enberg, 1968) the work of Jones and Miles published in 1978 appears to represent the initial scientifically-based sport-specific examination of anticipation in skilled performance. Jones and Miles developed a task in which subjects were shown film extracts of the serving action of an elite tennis player filmed from the receiver's on-court perspective. Variable extents of advance and ball flight information were provided through selective editing of the film segments and the subjects, who were tennis coaches of different standards, were required, on each trial, to determine within which of three possible sectors in the service court area the serve would land. In all, three different cut-off time conditions were used - one condition showed 336 msec. of ball flight, a second condition showed 126 msec. of ball flight and a third condition occluded vision of the server 42 msec. prior to racquet-ball impact.

The results obtained demonstrated differences between the prediction performance of skilled coaches and novices only under the third condition in which only advance information was available. Under these conditions the skilled coaches demonstrated a prediction accuracy greater than chance levels (indicating that useful information was indeed available to them prior to ball flight) but less than that for the other conditions in which ball flight information was available (indicating that the pre-flight cues provide only partial and not total predictability of the ensuing ball flight). The prediction accuracy of the novice group on
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<td>Enberg (1968)</td>
<td>anticipation of direction of tennis</td>
<td>63 women U/Gs classified as team players, beginners or novice players</td>
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<td>directional error in landing position predictions on a scaled tennis court representation</td>
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<td>no significant differences in prediction error noted between skill groups; tendency for tennis players to underestimate stroke depth</td>
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<td>Jones &amp; Miles (1978)</td>
<td>anticipation of direction of tennis serves</td>
<td>11 professional coaches with top-level playing experience; 21 other professional tennis coaches; 60 undergraduate students with no competitive tennis experience</td>
<td>(a) 8 frames after contact; (b) 3 frames after contact; (c) 1 frame before contact</td>
<td>selection of either down-line, court centre or wide service directions</td>
<td>analysis of variance</td>
<td>significant differences between groups (in favour of the top coaches) on the earliest temporal occlusion condition; no differences evident between groups with ball flight variable</td>
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<td>Patrick &amp; Spurgeon (1978)</td>
<td>anticipation of direction of a penalty kick in soccer</td>
<td>details not available</td>
<td>variable previews leading from the run-up to the point of contact with the ball</td>
<td>4 choice response regarding corner of net to which kick is directed</td>
<td>details not available</td>
<td>information available prior to the kicker's contact with the ball allow the penalty kick direction to be predicted beyond chance levels</td>
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<td>Salmela &amp; Fiorito</td>
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<td>34 young ice hockey goaltenders (mean age 15.8 years)</td>
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<td>anticipation of direction of a spiked volleyball</td>
<td>40 volleyball players of senior, junior and recreational level</td>
<td>(a) complete display information including ball trajectory; (b) contact point; (c) 2 frames prior to contact; (d) 4 frames prior to occlusion</td>
<td>(a) verbal indication as to which of 3 targets the ball was directed to (non-time-stressed); (b) physical dive to the simulated target position on the laboratory floor (time-stressed condition)</td>
<td>details not available</td>
<td>.experienced players showed superior anticipatory ability under the non-time-stressed condition; prediction errors increased dramatically when real time-stresses were introduced and movement response was required</td>
</tr>
<tr>
<td>Isaacs &amp; Finch</td>
<td>anticipation of direction of tennis serves</td>
<td>34 beginning and 16 intermediate tennis players</td>
<td>(a) 30 msec after contact; (b) 15 msec after contact; (c) contact; (d) 10 msec before contact</td>
<td>both lateral and depth errors in the prediction of landing position on a scaled tennis court representation</td>
<td>analysis of variance</td>
<td>.anticipation of service direction from advance cues was superior for the intermediate players; with ball flight available directional judgement was superior to depth judgement</td>
</tr>
<tr>
<td>Study</td>
<td>Sport Task Examined</td>
<td>Subjects</td>
<td>Occlusion Used</td>
<td>Response Measure</td>
<td>Analysis Procedures</td>
<td>Conclusions</td>
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<tr>
<td>Abernethy &amp; Russell (1984)</td>
<td>anticipation of direction and length of a bowled cricket ball</td>
<td>18 male cricketers consisting of 6 first class, 6 first grade &amp; 6 lower grade batsmen</td>
<td>occlusion at the point of release of the ball by the bowler</td>
<td>verbal response selection decision</td>
<td>analysis of variance</td>
<td>trends in the direction of greater prediction occurring for the experienced batsmen (Groups 1 &amp; 2)</td>
</tr>
<tr>
<td>Lyle &amp; Cook (1984)</td>
<td>anticipation of the direction of a penalty flick in field hockey</td>
<td>10 hockey goalkeepers, 20 hockey players, 20 PE students and 20 non-players</td>
<td>variable filming perspective focussing upon (a) whole body (b) player's hand (c) upper body (d) lower body</td>
<td>4 choice response regarding corner of net to which shot is directed</td>
<td>descriptive analysis only</td>
<td>better prediction performance by goal-keepers than for other hockey players or non-players; region providing most important anticipatory cues could not be isolated</td>
</tr>
<tr>
<td>Starkes &amp; Deakin (1984)</td>
<td>anticipation of the direction of a penalty flick in field hockey</td>
<td>National level, varsity level and non-field hockey players</td>
<td>(a) 150 msec after impact; (b) 50 msec before impact</td>
<td>4 choice response regarding corner of net to which shot is directed</td>
<td>details not available</td>
<td>only the prediction performance of National level players exceeds chance when the display is occluded prior to contact</td>
</tr>
<tr>
<td>Jackson (1985)</td>
<td>anticipation of object direction in (a) fast bowling in cricket; (b) forehand return in tennis; (c) passing in netball; (d) penalty kick in soccer</td>
<td>40 sports-persons (PE students); 40 non-sports participants</td>
<td>all 4 situations occluded at the point of contact immediately prior to ball flight</td>
<td>2 choice (left-right) prediction on each task</td>
<td>non-parametric ( \chi^2 ) test</td>
<td>prediction of sports-persons was significantly above chance on all 4 tasks; prediction of non-sports persons was above chance on only one of the prediction tasks (soccer)</td>
</tr>
</tbody>
</table>
This third condition was not significantly greater than chance levels suggesting that the ability to use advance information may be related in a fairly direct manner to ball sport proficiency.

This film occlusion paradigm, in which the VT duration is externally controlled and constrained by the experimenter, has since been applied to a wide range of sports, with considerable variability between these studies in the occlusion times selected and the response measures used.14 (See Table 1 for a summary of these studies). Generally, despite these between-study variations, investigations of advance cue usage in the sports of soccer (Patrick & Spurgeon, 1978), ice-hockey (Salmela & Fiorito, 1979), volleyball (Soulière & Salmela, 1982), tennis (Isaacs & Finch, 1983), cricket (Abernethy & Russell, 1984: Experiment 2), field hockey (Lyle & Cook, 1984; Starkes & Deakin, 1984) and a collection of fast-ball sport situations (Jackson, 1985) have revealed repeatedly the utility of advance cues in response selection. Decisions based on advance cues only are made, almost without exception, at levels well in excess of chance. A superior ability of experts to extract advance information is also generally demonstrated with this superiority being most apparent under conditions of greatest temporal stress (i.e. the

14. Aside from the absence of a systematic approach to the problem of advance cue usage across studies with respect to the selection of occlusion conditions, it should also be recognized that there are inherent assumptions in this paradigm in terms of the selected occlusion times relating meaningfully to VT in the intact setting. Further there are a number of un-addressed limitations related to ecological validity in the maintenance of realistic time constraints and response modes, and in the presentation of display information by film. These collective limitations and assumptions are considered in greater detail in Chapter 4.
shortest VTs). Small sample sizes however, in many instances, preclude the clear demonstration of statistical differences between the skill groups.

In contrast to these film occlusion approaches, which essentially control for time and use prediction accuracy as the dependent measure of anticipatory performance, there are also some studies available which have taken the alternate tack of examining decision time whilst controlling error rates. Bard, Fleury & Carrière, for example, in a series of studies using schematic slides of basketball offences as stimuli (Bard, Fleury & Carrière, 1975; Bard & Fleury, 1976a, 1976b; Carrière, 1978) have demonstrated superior choice response times for expert performers, interpretable in terms of '... a greater perceptual flexibility for experts; that is, an ability to adapt more rapidly to perceptual alternatives' (Bard & Fleury, 1981, p. 35). These studies are however, open to criticism with respect to the ecological validity of the stimuli used. Schematic slide presentations, aside from failing to provide dynamic visual action of the type actually encountered in the sport situation, use a form of representation which may well, through familiarity differences alone, introduce bias in favour of the experienced game player.

More recently Tyldesley, Bootsma and Bomhoff (1982), whilst still retaining the use of static stimuli in the form of slides, provided advance information of the goal-kicking action of a soccer player and required subjects of different proficiency levels to make a two or four choice reactive response according to the perceived lateral and/or
vertical direction of the oncoming shot at goal. Comparison of the reaction times between groups of experienced and inexperienced soccer players revealed faster response times for the experienced players under all choice conditions. Interestingly however, no reaction time differences were evident between the groups when non-specific stimuli were presented. Clearly the more rapid responses of the expert performers are related to their ability to extract situation-specific anticipatory cues and are not due to a general all round capability for 'quick responding' - a finding reflected in other reaction time comparisons of performers in fast ball sports (e.g. Noe, Pauwels & Buekers, 1984; Ritzdorf, 1983; Ryan & Lakie, cited in Ryan, 1969).

Compatible conclusions to those drawn from the studies independently manipulating either response time or prediction accuracy are also evident from studies in which both the length of the VT and response accuracy are allowed to co-vary. For example, in the study by Abernethy and Russell (1984: Experiment 1) on cricket batsmen expert players were shown to be capable of making more accurate stroke-selection decisions than novices across a wide range of VT's, although there were differences observed in the willingness of the groups to trade-off speed for accuracy. Similar findings of response accuracy superiority for expert sportspersons over a wide range of temporal stresses were also evident in the earlier work of Fleury, Bard and Carrière (1982).

Despite some obvious paradigmatic problems in the study of sport-specific anticipation within the laboratory setting, especially those associated with the simulation of display characteristics using film and
the simulation of 'real-world' motor responses through pencil-and-paper type responses, the literature available points quite strongly in support of the notion of expert fast ball sport performers being characterized by superior anticipatory capabilities. Fortunately a growing body of field research is now also available which supports these notions through data drawn from more ecologically valid research paradigms.

(b) Evidence from Field Studies

Day (1980) demonstrated the importance of advance cues in ball flight prediction in tennis by developing a procedure which was essentially a field equivalent of the film occlusion paradigm reported by Jones and Miles (1978) and their successors. Day had subjects (21 skilled junior tennis players) wear a head-mounted visor which was electronically configured to obscure the subject's vision at the instant their opponent's racquet struck the ball. Subjects were not required to make a return stroke but only to predict the landing position of the ball on the basis of pre-flight cues. Potential auditory information from the landing of the ball was masked using white noise.

Although skill group differences were not compared, some improvements in prediction accuracy over a 10 week training period were noted for this experienced group of subjects although more marked improvements in performance were observed on a comparable film occlusion test. Throughout the test and training period a more accurate lateral prediction of landing position than depth prediction was present (a finding also reported in a film task by Salmela and Fiorito, 1979) and
there was a consistent tendency to overestimate depth - a finding also evident in film-simulation tasks (e.g. see Enberg, 1968). Together these observations may suggest that ball flight cues function primarily to correct depth judgement whereas lateral judgement of ball flight can be made primarily from advance cues alone.

Whereas Day demonstrated similar findings with a field occlusion test to those revealed earlier from film occlusion studies, Bard and Fleury (1981) have shown that the reaction time differences to sport-specific stimuli evident between experts and novices in the laboratory setting also hold within field settings. Ice hockey goaltenders placed in a contrived match setting and faced with a number of shot options were found to have reaction times which were clearly dependent on their proficiency level. In a similar vein Jones (1974) reported earlier, in a strictly anecdotal manner, differences in the reaction times of tennis players measured within the field setting, and also reported that these response times to an opponent's stroke were amenable to practice, particularly if direction to relevant anticipatory cues was provided. Further elaboration as to what these anticipatory cues were, however, was not provided.

Although the studies of Day, Bard and Fleury, and Jones add ecological validity to the study of anticipation in terms of the stimulus presentation being as 'real' as possible, the data collection approaches used in these studies are still slightly invasive and the possibility cannot be discounted of the subjects altering their perceptual or response strategies either because of experimenter intervention for data
collection purposes or because of the mere knowledge that they were under experimenter observation and therefore subject to expectancy effects (e.g. see Barber, 1976; Rosenthal, 1966). In an attempt to overcome these potential problems Abernethy (1984) and Howarth et. al. (1984) examined anticipatory cue dependence in a totally non-invasive manner using high speed cinematography as the remote data-extraction media.

Adopting the premises of the operational model described in the previous chapter Abernethy (1984) examined the skill of cricket batting through phase-locked high speed cinematography with one camera providing detailed temporal information of the delivery action of the bowler (i.e. the stimulus) and a second camera providing a corresponding record of the action patterns of the batsman (i.e. the response). Estimation of the VTs from the film record of the MT onsets revealed that early gross positioning actions of the feet were made entirely upon the basis of advance information, available on average up to some 110 msec. prior to the release of the ball by the bowler, whilst the fine movements which controlled the downswing of the bat were made on the basis of more current information including up to, on average, the first 145 msec. of ball flight (see Figure 4). Timing of the movement action was facilitated by the use of an essentially constant backswing MT, initiated in all cases by the onset of an invariant cue within the run-up and delivery action of the bowler. Although the use of a small sample of expert and lesser skilled players precluded the attainment of statistical significance the apparent trend was in the direction of the experts using shorter VTs (and hence earlier advance cues) upon which to select their gross feet movements but longer VTs (and hence more current information)
EXPERTS

RELEASE POINT

BAT - BALL CONTACT

BAT MOVEMENT

FEET MOVEMENT

VTDOWN = 144.8 msecs.

SRT

MTDOWN

SRT

MTFEET

VTFEET = -113.07 msecs.

NOVICES

RELEASE POINT

BAT - BALL CONTACT

BAT MOVEMENT

FEET MOVEMENT

VTDOWN = 121.1 msecs.

SRT

MTDOWN

SRT

MTFEET

VTFEET = -74.26 msecs.

Figure 10: Comparative VT-MT strategies in the bat swing and feet movement actions of expert and novice batsmen (from Abernethy, 1984).
upon which to select their ultimate downswing action (see Figure 10). The impression that the skilled performer provides of 'having all the time in the world' may be an observable consequence of the experts greater use of early advance sources of information in the selection of appropriate movement(s) of the feet.

Howarth et al. (1984) ensured the highest degrees of ecological validity were preserved by examining anticipatory cue usage within actual competition games in squash. Again application of the operational model to examine how the time constraints in squash were overcome indicated that the expert players make their initial anticipatory movements significantly earlier than lower grade players apparently using advance information, rather than relying, as the lesser skilled do, upon later ball flight cues as the stimulus for movement initiation. These earlier anticipatory movements of the experts are undoubtedly related to their recognition of critical cue(s) signalling the commencement of either a totally redundant series of events or a series of events for which all possible alternatives are not equiprobable (Alain & Proteau, 1978; 1980).

Examination of anticipation using sport-specific stimuli, presented in either laboratory or field settings, therefore appears to support quite unequivocably the importance of advance cues in skilled performance—a finding in keeping with the important role assigned to advance sources of information in the performance of simple laboratory tasks and applied ergonomic tasks (e.g. see Branton, 1979; Witt and Hoyos, 1976). Furthermore the evidence available (see again Table 1) points strongly in support of the early contention of Whiting (1969) that
The expert will not only need to watch the ball for less of its flight, but he will also require less time to discriminate, program and make decisions on the information that he receives ...

(p. 35)

and also supports the contention that for experts the recognition of redundancy, and a capacity to use early cues, makes the fast ball sport setting more like a "'closed skill' in an 'open' situation" (Whiting, 1969, p. 10).

An ability to recognize critical cues or sets of cues presented quite early in the perceptual display in many fast ball sports clearly reduces the information processing load on the expert performer - the recognition of redundancy, as noted previously, reducing the quantity of information that has to be processed. Equally importantly, attention to the most relevant sources of information available, in addition to ensuring that the available attentional time and space is used more efficiently, also allows the quality of the information available for processing to be enhanced. Evidence related to differences in the specific cues attended to by expert and novice performers, and hence differences in the quality of the information processed, will now be considered.

(2) Differences in the Quality of Information To Be Processed

From the discussion that has preceded it may be expected that at least some of the differences in performance capability between experts and novices in fast ball sports may be due to differences in the specific cues used in order to extract task relevant information and in order to
perceptually analyze the display. Although potentially the same information is available in the display for all performers, differences in the allocation of attention throughout the display may contribute to the differences in anticipatory performance already observed. As Neisser (1976, p. 180) has observed with the less time-constrained skill of chess:

One of the characteristics of a good chess player is his skill in picking up relevant information from the board... The information that specifies the proper move is as available in the light sampled by the baby as by the master, but only the master is equipped to pick it up.

This ability to attend to only the most pertinent cue sources also make the expert performer less susceptible to attempts at deception by opponents (Carroll, 1972; Lyle & Cook, 1984) and, in turn, more adept at increasing the information processing requirements of their opponents through the discrete use of fakes etc. Such deceptive manoeuvres either direct their opponent's attention to irrelevant cues or delay their processing of critical cues (Glencross & Cibich, 1977).

With reference to Norman's (1968, 1969) model of selective attention presented earlier (see Figure 9) it is evident that there are two possible sources of differences in the specific cue usage adopted by experts and novices. Differences in selective attention may potentially arise from either

(1) differences in the way in which the perceptual analysis of the current environmental conditions is conducted
or (2) differences in the manner in which pertinence to probable events is assigned based on the performer's prior experience.

In view of recent work by Fleury, Bard and Carrière (1982) which indicates that differences in the performance of expert and novice sportspersons on perceptual/decision tasks is due to differences in both (1) the speed of encoding input information (i.e. the perceptual analysis) and (2) the speed of processing, retrieving and reorganizing information in memory (i.e. the pertinence functions), these two potential sources of performance variance warrant consideration in more detail.

**Differences in Performance of the Current Perceptual Analysis**

Research attempting to isolate differences in the manner in which experts and novices perceptually analyze the current input information available in fast ball sports has proceeded from, what has been termed by Starkes and Deakin (1984), both 'hardware' and 'software' perspectives. Studies adopting the 'hardware' perspective have essentially sought out physical differences in the mechanical and optometric properties of the visual systems of expert and novice performers. Studies adopting the 'software' perspective, on the other hand, have been more concerned with differences between skill groups in the analysis, selection, coding, retrieval and general handling of the available visual information, carried out within the physical constraints of the ocular system.
(a) Hardware Studies of Perception in Sport

Early studies seeking an 'eye factor' contributing to elite sports performance (e.g. Banister & Blackburn, 1931; Clark & Warren, 1935; Tussing, 1940; Winograd, 1942) directed attention primarily at the standard optometric parameters of static visual acuity and depth perception. Even from these early studies it was apparent that the demands of the standard stationary tests used to assess these parameters, such as the Snellen eye chart, were far different from the kinds of demands placed upon the oculomotor system by fast ball sports and clear relationships between sport proficiency and these optometric parameters were not forthcoming. Surprisingly, in many instances, elite athletes were found to have visual acuity levels below that of the population norm and this presence of uncorrected visual defects in many athletes remains a persistent phenomena even in more recent studies of sport optometry (e.g. Bauscher, 1968; Garner, 1977; Sherman, 1980; Tests correlate, 1981)

In an effort to gain a more realistic assessment of the type of visual perceptual skills required in fast ball sports more recent studies have attempted to equate dynamic rather than static visual acuity with fast ball sport performance. Although dynamic visual acuity (DVA) is consistently a more important factor in the performance of dynamic skills such as catching (Sanderson & Whiting, 1974, 1978), car driving (Hulbert, Burg, Knoll & Mathewson, 1958) and aviation (Ludvigh & Miller, 1954) than is static acuity, the amount of performance variance accounted for by DVA is still not substantial. Interest in DVA as an important parameter in skilled fast ball sport performance seems to persist however, (e.g. see
Sanderson, 1972, 1981; White, 1977) even though the evidence demonstrating the importance of OVA as a parameter capable of discriminating the elite sports performer from the novice appears quite equivocal (e.g. see Beals, Mayyasi, Templeton & Johnston, 1971; Morris & Kreighbaum, 1977). (For a more detailed review of the general dynamic visual acuity literature see Hoffman, Rouse & Ryan, 1981 or for a review of the sport-specific literature see Morris, 1977).

Examinations of the role of depth perception and stereoptic vision in fast ball sport proficiency were generated largely out of response to Banister and Blackburn's (1931) original work which reported a greater inter-pupillary distance, and hence a more desirable stereoptic configuration for depth perception, in superior college athletes. Subsequent examinations, although discarding the notion of inter-pupillary distance being important (Clark & Warren, 1935), have varied in the extent to which they have identified depth perception as a parameter capable of discriminating the expert performer from the novice. Using primarily the Howard-Dolman apparatus to measure depth perception and random dot stereograms to assess stereoptic vision a number of studies have appeared supporting the importance of highly developed depth perception capabilities in elite performance in sports such as tennis (Graybiel, Joki & Trapp, 1955; Herrold, 1968), basketball (Miller, 1960; Montebello, 1953), volleyball and fencing (Miller, 1960) and there are even some reports of discrimination between sports groups and player roles within specific sports, on the basis of stereopsis scores (Zimmerman & Lane, 1976). However, as is typically the case with studies using single optometric parameters, an equally impressive body of research
exists showing no difference in the depth perception of expert and novice performers (e.g. Barclay, 1938; Dickinson, 1953; Heimerer, 1968; Hellweg, 1973; Isaacs, 1981) and low correlations between depth perception (and stereopsis scores) and scores on a number of motor performance tests (Bailey, 1968; Ross, 1962; Tomlin, 1966; Zimmerman, 1970). Similarly although much is written on the importance of the associated skills of spatial perception (e.g. Cox & Fisher, 1975; Graydon, 1980; Meek & Skubic, 1971) and distance perception (e.g. Callington, 1981; Cockerill, 1981a; Rogers and Price, 1974) tests of these variables also do not appear capable of consistently demonstrating fundamental sensory differences between the vision of the expert and that of the novice.

Since the initial interest in acuity and depth perception measures, tests of 'hardware' variables in sport have extended to include a far wider range of optometric variables. Measures of peripheral visual range (e.g. Buckfellow, 1954; Cockerill, 1981b; Hobson & Henderson, 1941; Johnson, 1952; Williams & Thirer, 1975; Young & Skemp, 1959), colour vision (e.g. Cobb, 1967; Gavriysky, 1969, 1970; Graybiel et. al., 1955; Mizusawa et. al, 1983) and even eye colour (e.g. Hale, Landers, SnyderBauer & Goggin, 1980; Wolf & Landers, 1978) have been taken in attempts to find a single visual variable discriminating the expert fast ball sport player from the novice, but the findings on these parameters, like the earlier ones, have lacked consistency. When one considers the possible bias in terms of non-significant findings not reaching the publication process the evidence supporting 'hardware' differences as the basis for selective attention and performance differences between experts
and novices is not at all strong. Although perhaps over-stating the case a little Smith's (1961) conclusion that

... the role of visual ability has been greatly over-emphasized as being an important factor in attempting to explain the factors underlying individual differences in motor learning and performance (p. 33)

seems reasonably justified if one considers visual ability within the context of single optometric parameters. Even when multivariate measures of the various optometric parameters are taken in an attempt to assess the overall composite 'hardware' functioning of the visual system (e.g. Beitel, 1980; Blundell, 1984; Deshaies & Pargman, 1976; Katovsky, 1978; Mizusawa et. al, 1983; Summers, 1974) this form of measurement approach seems to fall short of providing definitive visual characteristics for the expert performer (Charness, 1981; Starkes & Deakin, 1984).

Although the visual hardware possessed by the individual performer may still be very important in setting the potential limits on performance (Neil, 1981; Rothstein, 1977a; Sherman, 1980) it appears that even at the elite level of fast ball sport performance defects in one or more aspects of vision can be compensated for by strengths in other visual processing mechanisms (Abernethy & Russell, 1983; Ross, 1962). This therefore casts doubt on the value of training programs (e.g. Getz, 1978; Harrison & Reilly, 1975; Revien & Gabor, 1981; Seiderman & Schneider, 1983) which attempt to maximize performance through enhancement of only the 'hardware' aspects of visual functioning. A more fruitful avenue for isolating proficiency-related differences and for enhancing fast ball sport performance may therefore be through the
examination of 'software' rather than 'hardware' aspects of visual perception.

In the section which follows examination will be made of how the available visual information obtained through the ocular 'hardware' is processed by both experts and novices and, in turn, how efficiently the programs and strategies for handling the input information operate for the different skill groups. As the ability to process information effectively is an acquired one which may be only partially related to the reception of visual information (Kaufman, 1974) the examination of visual 'software' in sport offers a new and relatively independent approach to skill group differentiation from that provided by the 'hardware' approach.

(b) Software Studies of Perception in Sport

'Software' analyses of skilled performance have been directed towards searching for systematic differences in information processing strategy between experts and novices - differences which are not attributable to differences in the physical ('hardware') components of the visual system. Because information processing strategies are very situation specific, 'software' analyses have generally proceeded through the use of sport-specific stimuli and thus offer, in most instances, more ecologically valid tests of visual functioning than are provided by the traditional 'hardware' approaches. To date some processing differences have been demonstrated between experts and novices in the ability to extract relevant information from both pre-flight and object flight cues
Figure 11: Apparatus and design of linear motion prediction tasks (from Abernethy and Russell, 1983).
in fast ball sport settings, to encode and retrieve perceptual information about fast ball sports, and to maintain appropriate attentional focus to avoid processing the distracting stimuli which abound in these settings. All these differences are compatible with predictions which can be derived from Norman’s selective attention model.

(i) Differences in Ability to Extract Object Flight Information

Accurate processing of information from the early flight of the ball (or equivalent) is obviously critical in fast ball sports in order to make the precise predictions of the temporal and spatial co-ordinates of the approaching ball necessary for successful coincidence-timing performance. Traditionally motion prediction (and coincidence timing) capability has been examined using linear tasks (Alderson, 1972) and standard apparatus such as the Bassin anticipation timer (Bassin, 1979; Dunham & Glad, 1976). Considerable emphasis has been placed upon using paradigms which are essentially linear analogues to those described earlier for catching tasks (see Figures 7 and 11) and the research has focussed mainly on isolating the key task and procedural variables influencing prediction performance (Alderson & Whiting, 1974; Bonnet & Kolehmainen, 1969; Ellingstead & Heimstra, 1969; Slater-Hammel, 1955). Nevertheless, a number of attempts to apply these linear motion prediction tasks to the study of anticipation in fast ball sports have been made (e.g. Nettleton, 1979; Nettleton & Smith, 1980) but these have been generally incapable of discriminating expert sport performers from novices (Blundell, 1984; Del Rey, Whitehurst, Wughalter & Barnwell,
Figure 12: Apparatus and design of curvilinear motion prediction tasks (from Abernethy & Russell, 1983).
Problems of ecological validity associated with the use of stimulus velocities markedly lower than those encountered in fast ball sports, the use of linear rather than curvilinear motion paths and the removal of the stimulus object from its game context, all detract from the applicability of this form of testing to the examination of skill group differences (Abernethy & Russell, 1983; Alderson, 1972; Davids, 1982).

Sport-specific versions of the linear coincidence-anticipation tasks have been developed (e.g. see Hilliard, 1970; Toburen, 1977) but the demonstration of clear proficiency-related differences in the processing of ball flight information appears to necessitate, quite specifically, the provision of real ball flight information. When real rather than apparent object flight is provided in the motion prediction tests, usually through the use of ball projecting apparatus (see Figure 12), and actual movement responses are required, reliable skill group differences are frequently reported. Studies showing superior prediction accuracy for expert fast ball sport performers on these types of field tasks in comparison to both novices (Buekers & Pauwels, 1981; Williams, 1969) and elite 'closed-skill' sports performers (Bard, 1974a, 1974b) are available indicating possible 'software' differences in the processing of ball flight information which are proficiency-related. The existence of some field studies which have failed to reveal these systematic effects however, (Crow, 1969; Molstad, 1974) draws attention to the need to also consider the contextual (advance) cues which also normally accompany ball flight. Provision of these sport-specific advance cues, it has already been noted, allows clear differences in the visual information processing
capabilities of expert and novices to be demonstrated.

(ii) Differences in the Recognition and Encoding of Display Structure

The literature demonstrating differences in anticipatory capability between experts and novices, which was reviewed previously within the context of information reduction, can now be considered within the current context as a fundamental 'software' difference. These differences in anticipatory performance between experts and novices, it now appears, are related largely to the expert's greater ability to recognize structure and 'stimulus patterns' within the sport-specific display and an impressive body of literature is now available to support the existence of a memory for environmental structure which is situation-specific. Arising originally from the work of de Groot (1965, 1966) in which chess masters were shown to have a superior recall capacity for chess pieces displayed in game-specific configurations but not in random configurations, the skill-specific memory effect has been shown subsequently to be a robust one holding not only for chess (e.g. Chase & Simon, 1973a, 1973b; Charness, 1976; Frey & Adesman, 1976; Goldin, 1978; Holding & Reynolds, 1982; Lane & Robertson, 1979) and other board games (e.g. Charness, 1979; Engle & Bukstel, 1978; Reitman, 1976), but also for more diverse cognitive activities such as reading music (Sloboda, 1976) and maps (Howard & Kerst, 1981) and recalling circuit diagrams drawn by electronics technicians (Egan & Schwartz, 1979).

Application of this recipient paradigm to the examination of the role of structure in the recognition of sport-specific stimuli has been
made primarily through the work of Allard and her associates at the University of Waterloo (Allard, 1980, 1982; Allard, Graham & Paarsalu, 1980; Allard & Starkes, 1980; Starkes & Allard, 1983; Starkes & Deakin, 1984). In research done initially with basketballers (Allard et. al., 1980) and later with field hockey players (Starkes & Deakin, 1984) of different calibre, the more proficient players have been consistently characterized by a superior recall capability for structured game information (such as offensive plays in basketball) but not for unstructured material (such as warm up drills or turnover situations). This interaction between proficiency and display structure is taken as indicating that the observed differences are due to differences in 'software' specifically related to the recognition of structure in these game settings and not to a general superior recall capability for elite sportspersons.

Concurrent attempts to demonstrate the persistence of this effect in the game of volleyball by Allard and Starkes (1980) have not been successful, although this may well be a consequence of the nature of the task used and the failure to consider the respective pertinence of the position of front-line and back-line players to the offensive structure in this sport. When these structural constraints imposed by the rules of volleyball are considered and display information is presented in a dynamic rather than a static manner, the expected superiority of expert players in the recall of structured but not unstructured offensive patterns is demonstrable (Borgeaud & Abernethy, 1985). Similar demonstrations of recognition and recall superiority are also now
available for expert rugby players searching for weak points in the
defensive patterns of an opposing team (Nakagawa, 1982) and for expert
gymnastic coaches searching for set positions within a gymnastic
activity (Imwold & Hoffman, 1983).

The weight of available evidence therefore appears to indicate
fundamental differences in the 'software' used by experts and novices to
analyze the display, especially in terms of the programs used for
'feature detection' and 'pattern recognition', and it seems logical to
presume that this superior recognition of display structure contributes
to the superior anticipatory skills of the expert observed previously.
The rapid and accurate recognition of display structure by experts
provides not only a basis for guiding the current sensory analysis but
potentially also, through the encoding process, a means of adding to the
data base of pertinent experiences which can be used to guide the
selective attention process in future, similar instances. The possession
of a vast knowledge base of pertinent information seems fundamental to
the adaptability characteristic of skillful performance (Chase & Chi,
1980) and it is, as Whiting (1982, p. 10) suggests, that

... experience in a particular sporting situation
leads over time to the build up of a "knowledge
base" about that game which as well as being
specific is organised in an hierarchical manner.

The skilled person may have quicker access to this knowledge
structure, thereby facilitating anticipation and prediction (Keele,
1982), although it should be recognized that the invariant nature of much
of the available perceptual information within the display may make it
unnecessary for much of the specific detail of past perceptual experiences to be actually stored in memory (Gibson, 1966, 1979; Kelso, 1982b, p. 142).

In summary, the role of structure recognition in skilled performance is a clear example, within selective attention terms, of the matching between current sensory inputs and the pertinence inputs derived from prior experience. Effective performance appears to necessitate a high degree of internal structuring and organization by the performer generally in his/her approach to environmental problems and even in wholly cognitive tasks (Chiesi, Spillick & Voss, 1979; Elstein, Shulman & Sriefka, 1978; Hunter, 1968; Larkin, McDermott, Simon & Simon, 1980; McKelthen et al. 1981; Schoenfeld & Herrmann, 1982) expert performers are characterized by problem solving strategies which are indicative of a high degree of organization. Experts appear to use, or at least have access to, perceptual 'software' structured in a superior manner to that at the disposal of a novice.

(iii) Differences in Susceptibility to Distraction

The ability to recognize pertinent structural features within the perceptual display necessitates an attentional strategy which focuses upon relevant display cues alone and which in turn, makes the performer less susceptible to distraction from irrelevant sources. Some tentative evidence is available to demonstrate fundamental differences in the susceptibility of expert and novice fast ball sport performers to distracting stimuli.
Studies using standard tests of field dependence/independence (after Witkin et al., 1962), such as the embedded figures test or the rod and frame test (see Jones, 1973; Nettleton, 1979), have attempted to assess the relative capability of expert and novice sport performers to focus primarily upon a pertinent figure without being distracted by the movement, texture or general perceptual properties of the background field. The predicted difference in selective attention performance on the basis of this measure of perceptual style is that

... field-dependent persons are greatly affected by distraction, whereas field independent persons are able to ignore irrelevant stimuli and direct their attention to the important information. (M. G. Jones, 1972, p. 107)

Although there are some positive findings indicating greater field independence for elite athletes in sports such as tennis (Kreiger, 1962; Rotella & Bunker, 1978) and football (Pargman, Schreiber & Stein, 1974), in individual sports (Bard, 1972) and in catching tasks where the VT is restricted (MacGillivray, 1979) these differences usually account for relatively small portions of performance variance (Docherty & Boyd, 1982). Studies failing to differentiate skill groups on the basis of perceptual style abound (e.g. Enberg, 1968; Lindquist, 1978; Petrakis, 1979, 1981; Williams, 1975) and there are even some contradictory reports of the elite performer being characterized by greater field dependence rather than independence (Barrell & Trippe, 1975). (For reviews of this literature see Sloan, 1976 or MacGillivray, 1981).

Consistent reference has been made to problems with the validity of the measurement instrument for perceptual style (MacGillivray, 1980),
especially with respect to between-test variability (Arbuthnot, 1972; Sloan, 1976) and the use of static rather than dynamic test items (Herkowitz, 1972; Pargman, Bender & Deshaies, 1975). These problems of ecological validity within the test's design may well preclude performers from using the same specific processing 'software' in the test situation as they would in the sport setting. Although some relationship has been shown in field settings between these measures of perceptual style and measures of selective attention (Mihal & Barrett, 1976) a more appropriate approach to assessing selective attention in fast ball sports would appear to be through the use of tests in which multiple facets of attention, such as attentional breadth and focus, rather than single attentional dimensions, are examined.

One such test, Nideffer's (1976) Test of Attentional and Interpersonal Style (TAIS), which has been used substantially in the contemporary sport psychology literature, attempts to tap some of these aspects of selective attention important in stressful and competitive performance situations, by considering attentional style both in terms of breadth and direction. Using a 144 item pencil and paper test consisting of six scales for the assessment of adequate, and inadequate, attentional breadth (broad vs narrow) and focus (internal vs external) the TAIS operates, according to Nideffer (1979), under the premise that if an athlete is to perform to his full potential he must

... learn what to attend to, when to attend to it, and how to be able to maintain that attention at the critical time. (p. 99-100)
An athlete's susceptibility to distracting stimuli is expected to be shown in the TAIS through high scores on the scales of OET (Overloaded by External Stimuli), indicating confusion due to excessive environmental stimuli, OIT (Overloaded by Internal Stimuli) indicating a difficulty with handling multiple intrinsic thoughts simultaneously and especially RED (Reduced Attentional Focus) indicating an inability to avoid errors due to excessive narrowing of attention.

Differences between successful and less successful swimmers were reported by Nideffer (1977) as support for the validity of the TAIS and in some instances subsequently the TAIS has been found to be capable of discriminating expert and novice sports performers in the directions hypothesized (e.g. Buckles & Beitel, 1984; Kirschenbaum & Bale, 1980; Richards & Landers, 1981). In quite a number of cases however the TAIS in its original form has been shown to be incapable of discriminating attentional differences between experts and novices (e.g. Aronson, 1982; Landers, Furst & Daniels, 1981) and even in the case where skill group differences are found these are often not on the subscales predicted (e.g. Jackson, 1981) or do not account for sufficient performance variance to allow prediction of performance to be made with certainty on the basis of the TAIS (Zaichowsky, Jackson & Aronson, 1983). Difficulties in terms of failure to consider all appropriate forms of sport attention, including the performer's capacity for attentional flexibility and the distinction between the attentional processes of scanning and focussing have been alluded to in the literature (Etzel, 1979; Van Schoyck & Grasha, 1981; Zaichowsky, 1984). The principal criticisms and modifications to the original test have however, been
related to the necessity to incorporate sport-specific items (e.g. see Mann, 1984).

Development of sport-specific forms of the TAIS for use with tennis players (Van Schoyck & Grasha, 1981) and soccer players (Taylor, 1981) have improved the discrimination of skilled players from novices in comparison to the original TAIS form but there still appear problems with trying to assess attentional performance in this way. The relatively poor correlation between the TAIS sub-scale scores and behavioural measures of attentional performance15 (e.g. see Nettleton, 1984; Reis & Bird, 1982; Vallerand, 1983) suggest an inadequacy in the use of pencil-and-paper-type tests to measure these aspects of sports performance which are so complex. Therefore, although only some tentative support for differences in susceptibility to distraction between experts and novices can be derived through both measures of field dependence/independence and the TAIS this lack of systematic evidence would appear to be more indicative of the absence of an adequate measure of sport-specific selective attention and attentional style than indicative of the absence of any 'software' differences in these aspects of performance.

Overall then there appears to be a number of differences in the manner in which expert and novice fast ball sport performers perceptually analyze the displays available in their specific sports and these differences appear to be related primarily to differences in the

15. With the data collected from experiments reported later in this thesis a poor match between sport-specific TAIS sub-scales and behavioural measures of selective attention performance was again observed.
perceptual strategies used. Although 'hardware' aspects of the performer's ocular system may set the potential limits to the visual-perceptual performance of any player, the real differences between the perceptual performance of the expert and the novice appear more directly related to the information processing strategies used in extracting information from ball flight, in recognizing structure and redundancy in the events preceding ball flight and in terms of generally directing attention to only those most pertinent aspects of the immediate environment. The allocation of attention, it has been noted previously, is determined not only by the currently available sensory information but also by the expectational and contextual information acquired from experience. The role of these pertinence inputs to the selective attention process have already been considered in respect to many of the 'software' aspects of performance. It remains now to consider some of the other possible differences between the selective attention of experts and novices evident in the differential assignment of pertinence.

**Differences in the Assignment of Pertinence to Possible Events**

In classical laboratory settings choice reaction time (CRT) is directly proportional to the amount of input information regardless of how the information processing load (or uncertainty) is manipulated (Hick, 1952; Hyman, 1953). Under conditions of practice however, the effective information processing load faced by the subject appears to decrease substantially (Conrad, 1962; Mowbray & Rhoades, 1959) to the point where, after extensive practice, the display uncertainty and CRT may appear to be almost un-related. The reduction in decision time which
### TABLE 2

Examples of means of reducing event uncertainty in racquet sports (from Abernethy & Russell, 1983).

<table>
<thead>
<tr>
<th>Strategy for Reducing Uncertainty (from Hyman, 1953)</th>
<th>Racquet Sport Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decrease the Number of Possible Alternatives</td>
<td>Experienced player may recognize that there are only two possible responses in receiving service i.e., the forehand or backhand drive. The volleys and smash are recognized as impossible response alternatives off the service.</td>
</tr>
<tr>
<td>Recognize Differences in Event Probabilities</td>
<td>Experienced player may recognize that an opponent retrieving a ball in the backhand court is more likely to toss from that position than play a drop shot i.e., the two events are viewed as not equiprobable.</td>
</tr>
<tr>
<td>Recognize Regularities in the Order of Events i.e., Sequential Dependencies</td>
<td>Experienced player may recognize that in any particular rally his opponent's movement to the net will follow immediately after any deep return to the backhand side i.e., the opponent's net movement is contingent on the previous event sequence.</td>
</tr>
</tbody>
</table>
occurs with practice is most likely the result of subjects developing expectancies related to the number of stimulus-response alternatives, the probability of occurrence of individual stimuli and the sequential dependencies in stimulus presentation (Hyman, 1953) - expectancies which are quite accurate representations of actual event probabilities. Any advance knowledge the subject derives regarding alternate events being non-equiprobable, by definition, decreases the information processing load, thereby facilitating the production of a more rapid response.

In the applied setting of the fast ball sport the expert performer's experience may also allow realistic expectancies of forthcoming events to be formulated thus enhancing the making of both accurate and rapid responses to the occurrence of certain environmental events. Comparable examples can be found in sport settings to the manipulation of event uncertainty achieved through varying the number of alternatives, the probabilities of events or the sequential dependencies in laboratory settings (see Table 2) and indeed accurate expectancies of forthcoming event probabilities through any of these avenues may characterize the perceptual set of the experienced fast ball sport performer (Glencross, 1978c, p. 112).

The number of stimulus alternatives in many sports can be reduced quite drastically by eliminating the possibility of some events occurring entirely. Poulton (1965, p. 41), for example, presents the argument that

... in hockey a skilled player knows that his opponent will not hit the ball just anywhere. ... Eliminating the other alternatives at an early stage can reduce the player's reaction time once the ball is hit,
and there is some evidence using sport-specific stimuli to suggest that experts recognise the number of response alternatives virtually automatically whereas this takes time for novices (Carrière, 1978). Similarly, knowledge of unequal event probabilities in sport may facilitate the response processes as exemplified in the observation by Hutt (1972, p. 249) that

... an average badminton player under pressure to retrieve the shuttlecock in the back court is more likely to execute a deep clear shot than a smash or a drop shot thereby enabling the receiver to position himself for an appropriate return.

In the same manner knowledge of event sequences, or sequential dependencies, has also been shown to provide a valuable source of pertinence information for the reduction of CRT in sequential skills such as fencing (Schubert, 1981) and for the reduction of errors in coincidence-anticipation tasks of the type prevalent in fast ball sports (Haywood, Greenwald & Lewis, 1981).

A logical expectation with respect to fast ball sport performance is therefore that the expert performer may have a more precise knowledge of event probabilities than is possessed by the novice and it may be this expectational information that is used by the experts in guiding their assignment of pertinence, their selective attention and ultimately their skilled performance. This would appear a particularly viable hypothesis given the advantage that expert players have in being able to influence their opponent's actions in the competitive setting, thereby directly influencing some of the critical event probabilities (Hammond, 1975, p. 147). The expert performer may be better able to use his reservoir of
past experiences to make 'best-bet judgements as to what will likely happen in a given situation' (Marteniuk, 1976, p. 98) and may be better equipped to adopt decision-making criteria which approach more closely statistically optimal levels (Whiting, 1979) than is the novice.

Despite the suggestion that with increasing age and experience the subjective probabilities held by an individual come to match more closely the objective probabilities in any situation (Cohen, 1957), and the observation of a close match between the subjective estimates held by skilled soccer players of their probability of scoring from given distances from goal and their actual performance (Cohen & Dearnaley, 1962), there are fundamental difficulties in examining experimentally the subjective probabilities held by any performer in fast ball settings. As the subjective probabilities used by skilled sport performers carry no absolute value (Cohen & Christensen, 1970) they may be outwardly irrational and meaningless to the external observer and, in many cases, even the skilled performers may be totally unaware of the probabilities they themselves adopt (Whiting, 1979). To examine the role of probability and expectational knowledge in sport therefore constitutes an experimentally difficult problem.

Two fundamentally different approaches to the problem of subjective probabilities in sport are apparent in the literature, both emanating largely from the work of Alain, Proteau and co-workers at the University of Montreal (Alain & Proteau, 1977; 1980). One approach proceeds by making objective measurement of the occurrence of particular events within the intact sport setting to see if players actively attempt to maximize
the situational uncertainty presented to their opponents. The alternate approach attempts to simulate game demands by presenting objective event probabilities to subjects in a comparable manner to that traditionally used in the manipulation of uncertainties within laboratory CRT tasks.

As an example of this first approach, Carrière and Breton (1976), analyzed an international volleyball competition for examples of active attempts to vary the temporal, spatial, and event uncertainties associated with attack phases, and concluded that the manipulation of these factors to maximize uncertainty seemed to be related in some way to the competitive outcome. In a later study Alain and Girardin (1978) calculated actual event probabilities in racquetball competitions and found conversely that players do not appear to actively attempt to maximize event uncertainty (by making different stroke selections equiprobable). They concluded that an attack strategy to maximize event uncertainty may not be necessary in this setting because of the severity of the time constraints already imposed on the decision-making processes of the opposing player. Nevertheless their observation that all event occurrences within such a fast ball sport setting are far from equiprobable highlights the viability of a knowledge of event probabilities in facilitating rapid decision making.

In a companion study Alain and Proteau (1978) attempted to determine the extent to which defensive (receiving) players in racquet sports use event probabilities to anticipate the stroke selection of their opponent. Using a procedure in which rally situations from racquetball, squash, tennis and badminton were filmed and the participating players questioned
after each rally to determine what they considered to be the likelihood of their opponents selecting particular strokes, a high association was found to exist between the frequency of the player's anticipatory movements in specified directions and the subjective probabilities they assigned to events requiring such directional responses. This was seen as evidence for the role that expectational and probability information plays in guiding anticipatory movements and a two-stage response process was hypothesized in which initial anticipatory movements were made on the basis of subjective probabilities and more rapid subsequent corrective or confirmative movements were made on the basis of current information.\textsuperscript{16} The threshold for making anticipatory movements in these settings occurred when subjects became over 70\% certain that a particular stroke would be produced by their opponent (see also Proteau & Alain, 1983), thus justifying the general conclusion that

\begin{quote}
...players appear to evaluate, and to use to their advantage, the difference in the probabilities subjectively assigned to the different shots capable of being used by the adversary. 

(Alain & Proteau, 1980, p. 468)
\end{quote}

The acquisition of an accurate data base for use in generating subjective probabilities would therefore appear to be an important part of developing skill in fast ball sports but unfortunately, to date, little investigation of proficiency-related differences in subjective probability use have been made within this paradigm. More recent

\textsuperscript{16} Given that probability information seems to facilitate anticipation this two-stage response proposition becomes not dissimilar to the form of response strategy which appears evident in skilled cricket batsmen. (See Figure 4).
attempts have been directed at mathematically matching the subjective probabilities held with the extent of anticipatory preparation (Alain, Lalonde & Sarrazin, 1982), although to date this modelling has not been entirely successful in allowing the subjects' selection of preparatory state to be predicted (Alain & Sarrazin, 1984).

Studies attempting to replicate these probability effects in laboratory tasks in which subjects are provided with objective probabilities have met with considerably less success, and have been singularly unable to discriminate between the use of probability information by proficient and lesser skilled fast ball sport performers (Alain & Bourgeois, 1982). Within these laboratory CRT settings subjects appear to adopt a very conservative decision strategy, being reticent to use probability information to facilitate decision speed until two choice probabilities reach the order of 9:1 (Alain & Proteau, 1977; Proteau & Dugas, 1982; Proteau & Laurencelle, 1983; Regnier & Salmela, 1980), and this effect holds even in situations where they are given instructional sets biased in the direction of response speed (Proteau, Teasdale & Laurencelle, 1983). The problems encountered in this second research tack appear to reflect the essential difference between providing objective probabilities and having subjects formulate their own subjective probabilities on the basis of their personal experience - subjects generally being willing to place more weight on self acquired information than on information acquired from external sources (Singer, 1980; Singer & Gerson, 1981). Therefore although expert performers may well vary from novices in the subjective probabilities they adopt, and the pertinence they assign to different potential events within the
display, the demonstration of these possible differences is, to date, very limited, restricted largely by the absence of a suitable, ecologically valid, investigative paradigm.

To summarise thus far, the process of selective attention has been seen to include the selection of relevant stimuli for detailed processing based on the integration of pertinent information arising from both the current environment (mediated through the processes of sensory analysis) and past experience (mediated through the performer's expectational and contextual knowledge). Differences in the processing strategies used by expert and novice performers in handling the current input information from both anticipatory and ball-flight sources have been demonstrated, with these 'software' differences in sensory analysis occurring apparently quite independently of any 'hardware' differences in the optometric functioning of the visual system. Differences in ability to recognize display structure within the sporting environment have been highlighted, indicating the important role of memory processes in selective attention, but to date attempts to show proficiency-related differences in awareness of event probabilities have been less successful.

The evidence considered to date regarding proficiency-related differences in visual selective attention in fast ball sports has been somewhat indirect, being dependent largely upon traditional scores of speed and accuracy to imply strategy differences. A more direct approach to examining possible differences in selective attention between experts and novices is through the specific examination of visual search
Figure 13: A two-stage model of visual search with selective attention as the mediating process between pre-attention and focal attention. Alternative classifications of this two-stage process are also shown.
strategies attained through eye movement recording methodologies. Visual search evidence contributing to understanding of the process of visual selective attention in fast ball sports will now be considered.

III THE VISUAL SEARCH PROCESS

Stages of the Visual Search Process

Visual search is usually conceived of as a two stage process involving an initial capacity-free pre-attentive stage, in which all visual information available from the receptors is held very briefly in literal representation in a rapidly decaying visual sensory store (the icon), and a subsequent attention-demanding focal stage of performance in which selected items from the iconic store are subjected to detailed analysis (Neisser, 1967) (See Figure 13). Selective attention may be considered as just one of the components of visual search, specifically concerned with continuously guiding the passage of information from pre-attention to focal attention (Duncan, 1985). The specific structural locus of selective attention may vary from situation to situation, however, in that the actual selection process may occur at one or more stages of the information processing chain (Acosta & Simon, 1976; Thomas, 1980) depending upon the specific task requirements.

Within this framework, the performer's contextual and expectational knowledge may act to influence response selection in one of two ways - either through the normal influence upon the selective attention process
or through direct action upon the response selection process. This latter point of action allows explanation of how perceptually similar display situations may be responded to quite differently dependent on the performance context e.g. how a tennis player might respond differently to an identical stroke from his/her opponent dependent upon the game score.

The pre-attentive stage of analysis is usually conceived of as being automatic (La Berge, 1981; Neumann, 1984; Schneider, 1976), allowing the parallel processing of all concurrent input signals in a non-attention demanding manner (Salmoni, 1975). These concurrent input signals are believed to be held in a quite literal representation in the visual sensory store but are available to the performer for only a very brief period of time - the information held in this store being subject to very rapid decay in the absence of attention (Sperling, 1960). In this time very crude feature analysis of this sensory information is presumed to take place (Neisser, 1967) with the results of this analysis being used to determine those aspects of the display worthy of more detailed focal analysis. Both retinal (Long & Sakitt, 1980; Sakitt, 1975) and visual cortical (Di Lollo, Lowe & Scott, 1974; Taylor & Brown, 1972) loci have been proposed for this visual sensory store, or icon (Neisser, 1967), but considerable uncertainty now exists as to whether the icon exists in reality or is merely an artifact of the experimental paradigms used to study it (Dick, 1974; Haber, 1983). In any case application of current knowledge regarding iconic memory directly to the consideration of visual search within fast ball sport settings is extremely difficult given the severe absence of ecologically valid
investigations of the phenomenon. As Sharp (1978, p. 5-6) notes

... the value of sensory storage as a general theoretical concept is limited for its investigation has been delimited almost totally to the experimental situation where a stationary subject views a static field as in letter or form recognition. There is little evidence available which allows us to extrapolate from the static case to the dynamic one where there is relative movement between the visual field and the individual ...

Although the pre-attentive analysis of visual information may well be an essential stage in skilled performance in 'real' skills a more critical current concern is with determining what information the fast ball sport performers of different skill levels regard as sufficiently pertinent to commit to detailed focal attention. Examination of the cues reaching focal attention may provide an insight into the visual search patterns which characterize the elite performer.

In contrast to the difficulties encountered in studying pre-attentive aspects of visual search, reasonably accurate eye movement recording procedures are now available to examine focal attention within quite a wide range of experimental settings. As the eye constantly moves to foveate upon those features of the display of greatest current interest (Gaarder, 1975), and hence upon those display features being subjected to focal attentive analysis, the use of eye movement recording procedures provides a means of directly investigating the focal aspects of visual search. In the experimental setting consequently, examinations of visual search are generally restricted to studies of focal attention alone, with changes in the ocular fixation characteristics being matched to concomitant changes in display features. The parameters of fixation
location (as indicative of cue pertinence) and fixation duration (as indicative of search rate) are reported most frequently and these are parameters which are quite akin to the quality and quantity concepts of information processing used in the earlier behavioural assessments of selective attention in this chapter.

Cognitive and Applied Visual Search Research

Within these studies of focal attention an important distinction can be drawn between, what has been termed by Monk (1976), cognitive and applied visual search research. In cognitive visual search research the specific search task is of minimal interest to the researcher and serves merely as a vehicle for studying the underlying cognitive processes. The search material used is generally alphanumeric, because of its standard nature and ease of generation, and is usually presented in a form which is conducive to a single, specifiable order of scanning. This cognitive form of research has focussed principally upon the issues of developing models of search time (e.g. Drury, 1975) and identifying the factors influencing search speed (e.g. Drury & Clement, 1978; Mocharnuk, 1978). Reviews of this research may be found in Teichner and Krebs (1974), Barber (1981), Kerr (1982, pp. 153-157) and Wickens (1984, pp. 259-261).

Applied studies of visual search, on the other hand, place great emphasis upon the use of situation-specific tasks as the task performance is of central concern to the researcher. The tasks and procedures used do not place restrictions upon the order of scanning that can be used by the subject, as do the cognitive paradigms, and individual variability in
the search strategies used is of principal interest. Although there is
the emergence recently of some bridging studies which attempt to examine
cognitive questions through the use of more realistic stimuli (e.g.
Scanlan, 1977; Silbernagel, 1982), it is clearly necessary in order to
examine issues of relevance to this thesis to adopt the applied approach.

The majority of applied visual search literature available to date
has been concerned primarily with the application of visual search to
ergonomics, often with the objective of modifying task requirements or
equipment layout. Eye movement recording has been conducted in both
relatively static tasks, such as radar operation (White & Ford, 1960),
radiological examination (Kundel, 1974; Kundel & La Follette, 1972) and
industrial inspection (Megaw & Richardson, 1979; Schoonard, Gould &
Miller, 1973; Wentworth & Buck, 1982) and in tasks where the performer
moves at high speeds through the environment such as in driving (e.g.
Cohen, 1978a; Cohen & Studach, 1977; Mourant & Rockwell, 1970, 1972) or
flying (Llewellyn & Thomas, 1963; Milton, 1952; Stager & Angus, 1978;
Stern & Bynum, 1970). Obviously the latter tasks provide temporal
constraints and task difficulties which are more akin to the information
processing constraints of the fast ball sport setting, but the knowledge
accrued from the more static tasks is still useful in the field
assessment of the utility of the eye movement recording methodology (see
Chapter 4).

**Applied Visual Search and Selective Attention Notions**

The general findings regarding visual search in ergonomic tasks are
highly compatible with the predictions which can be derived from selective attention theory. The initial fixations of subjects in tasks such as radiographic inspection (Kundel & Wright, 1969; Kundel & La Follette, 1972) appear to reflect closely the subject's a priori expectations regarding the probable location of the most pertinent information whereas subsequent fixations appear to be determined by the flow of current information reaching the retina. These observable search strategies are very much in keeping with the earlier contentions from behavioural evidence (e.g. Alain & Proteau, 1978, 1980) regarding the order in which expectancy inputs and current sensory inputs exert their greatest influences upon the selective attention process.

Because the visual search of 'real world' displays appears to proceed largely on the basis of the subject's predictions of event probabilities some large sections of the display are very rarely sampled foveally (e.g. see Megaw & Richadson, 1979; Snyder, 1973) and search is largely restricted to those areas of the display with the highest perceived probability of containing pertinent information. Ambiguous and novel areas of the display appear to attract fixations (e.g. Kundel & Wright, 1969; Mackworth & Morandi, 1967) and there appears to be a relationship between fixation density and the rated informativeness of the display (Friedman & Liebelt, 1981). As the scan patterns follow closely the subject's subjective estimates of the location of important information (Mackworth & Morandi, 1967; Pollack & Spence, 1968; Schissler, 1969) the assignment of pertinence to display features appears to be, at least partially, cognitively mediated and the cognitive knowledge of the subject appears as an important factor guiding search
performance (Kundel & La Follette, 1972). Furthermore, in keeping with selective attention notions, the context in which the stimulus occurs appears to influence scanning activity (Antes & Penland, 1981; Shinar, McDowell & Rockwell, 1977), and a number of changes in critical search parameters occur with the induction of stress which reflect the corresponding decrements in selective attention performance (e.g. Kalunger & Smith, 1970; Mortimer & Jorgenson, 1972). Finally visual search appears to reflect a number of the known limitations of short-term memory\(^\text{17}\) - some locations in static displays for example, being searched a number of times in order to extract pertinent information (Wickens, 1984, p. 252). This observation, like the others, is compatible with the notion of visual search behaviour reflecting the selective attention process.

Given then that recording of visual search patterns appears to provide quite an accurate indication of selective attentive processes, what evidence is there of differences in visual search strategy which are proficiency related?

### IV PROFICIENCY-RELATED DIFFERENCES IN VISUAL SEARCH

1. **Ergonomic Task Literature**

   As a consequence of the relationships between inexperience and

\[17. \text{Because the selective attention process may be located in short term memory (after Norman, 1968, 1969), it should also acquire and reflect the functional limitations of short term memory.}\]
accidents (Kay, 1978), and perceptual errors and accidents (Lawrence, 1974), a number of studies in ergonomics have been concerned with comparing the perceptual performance of experienced and novice workers. In studies of mine workers for example, it has been shown that perceptual differences exist between experienced and inexperienced workers in their ability to discriminate safe and dangerous rock formations (Bignant, 1979a, 1979b), mirroring many of the perceptual differences noted earlier in behavioural studies of sport performers. Fortunately evidence is now available, from ergonomic settings at least, to show that many of these perceptual performance differences between experts and novices may be attributable to differences in the visual search strategies used. Specifically differences in terms of the specific cues foveated (i.e. differences in fixation location) and differences in the search rates adopted (i.e. differences in fixation duration) now appear within the search strategies of expert and novice performers.

(a) Differences in Specific Cues Fixated

Differences in the fixation locations of expert and novice performers viewing the same environmental display reflect differences in the quality of the information being processed. Ample evidence of proficiency related differences in fixation location, and hence in cue usage, exist.

In static tasks, where both the display and the viewer remain stationary, the clearest examples of proficiency related differences in the distribution of fixation locations are in the studies of radiography
(Carmody, 1980; Kundel, 1974; Kundel & La Follette, 1972; Kundel & Nodine, 1978). Skilled radiologists viewing a chest x-ray employ a search pattern which results in fixations being spread relatively evenly around the circumferences of both lungs - a fixation distribution that is very similar to an estimate of the probability distribution of abnormalities for the chest (Kundel, 1974; Kundel & La Follette, 1972). Laymen, on the other hand, have the greatest proportion of their fixations located upon the areas of sharpest visual contour i.e. the areas surrounding the heart and media-sternum - areas which are of relatively low pertinence for the isolation of chest pathologies. In other static tasks, such as searching numerical arrays for target items (Sperandio & Bouju, 1983), optimal search strategies also appear to emerge with practice.

Similar differences in qualitative aspects of visual search are available from comparison of expert and novice performers in tasks such as driving where there is relative movement between the human operator and the display. In the oft-cited works of Zell (1969) and of Mourant and Rockwell (1971, 1972), novice drivers were found to have fixations over a narrower horizontal range than experts in addition to forward fixations which were over a shorter distance than those used by the experienced drivers. Such scan patterns effectively prevented the novice drivers from having a broad awareness of potential vehicles or hazards entering from either their left or right sides and prevented them 'looking ahead' to anticipate the future task demands. Furthermore
novices made fewer fixations near the focus of expansion\textsuperscript{18} than did experts, thus impeding their efficient extraction of information regarding the forward motion of the vehicle, but conversely made greater numbers of fixations upon the edge of the roadway. These fixations to the road edge presumably assist in steering and positional control of the vehicle for the novice - functions which appear to be adequately controlled in experienced drivers through the use of peripheral vision (Bhise & Rockwell, 1971; Simonet, Ripoll & Papin, 1983). Finally, novice drivers were observed to make more fixations upon the speedometer but fewer on the rear vision mirror than experts. This observation supports the notion of an internal focus by the novice driver and is consistent with concepts of perceptual narrowing (Weltman & Egstrom, 1966). In summarizing these differences in visual search characteristics Rockwell (1972, p. 157) has noted that

\begin{quote}
\text{(inexperienced) drivers switch from frantic cue searching, large eye-movement travel distances and fixations on nonrelevant cues, such as lamp poles and guard rails, to alternate sampling near and far. The far fixations are thought to be primarily directional cues while the very near samples \ldots suggest foveal determination of lane position. The experienced drivers concentrate fixation on the focus of expansion and are thought to use peripheral or extra-foveal processes for lane positional feedback.}
\end{quote}

Considerable task specific experience appears necessary before the learner develops search strategies indistinguishable from those of the

\textbf{18.} The focus of expansion is that point in the visual environment to which movement is directed and is hence the stationary point from which all optic flow radiates. It provides the most specific environmental information available to the performer regarding the rate of forward motion and directional change (Fry, 1968).
experienced driver (Cohen & Studach, 1977; Helander, 1977). With such task-specific practice in ergonomic tasks the use of peripheral vision appears to increase, attention comes to be directed more automatically to pertinent features of the display, and the quality of information extraction is enhanced by use of a lesser number of environmental cues, each of greater pertinence (Neboit, 1983).

(b) Differences in Search Rate Used

Search rate, or the rate of making ocular fixation changes, can be expressed as either the number of fixations per second or, as it is more frequently, the mean fixation duration (\( FD \)). Search rate may be expected to reflect, in a reasonably direct manner, the information processing demands of the task with higher search rates, and hence shorter FDs, to be expected under conditions of high processing load (Teichner & Mocharnuk, 1979). Lower search rates, and hence longer FDs, would therefore be predicted for expert performers because of their more efficient processing of information and their relatively lower total processing loads.

In ergonomic tasks in which strict time constraints are not imposed upon the performer, such as in the radiological examination tasks, the experts appear to need fewer fixations in order to locate an anomaly, although their search rates are the same (Kundel & La Follette, 1972) or

\[ FD = \frac{\text{task duration}}{\text{the number of fixations}}. \]

19. Mean fixation duration is actually the inverse of the search rate i.e. search rate = fixations/second averaged over the task duration whereas FD = the task duration/the number of fixations.
even slower (Papin, Metges & Hernandez, 1983) than those of the untrained observer. Clearly in these cases the more rapid orientation to relevant information of the experienced viewer is due to their use of more pertinent cues and their superior expectancies regarding the potential location of such information.

When temporal stress is added to ergonomic tasks however, conflicting evidence appears to emerge regarding the search rate differences between expert and novice performers. In keeping with the predictions of Boynton (1960), superior performers in inspection tasks appear to need not only fewer fixations in order to detect item flaws (Schoonard, Gould & Miller, 1973) but also use a search strategy which is characterized by higher fixation rates, and hence shorter FDs, than are used by less competent inspectors (Krebs, 1975; Megaw & Richardson, 1979; Schoonard, Gould & Miller, 1973). Comparable evidence of shorter FDs for expert pilots (Senders, 1976; Stern & Bynum, 1970) and compatible findings of decreased FD with task-specific practice on a numerical searching task (Sperandio & Bouju, 1983), also support the somewhat unexpected conclusion of faster search rates for expert performers. On the other hand, there is conflicting evidence from flying (Neboit, 1983; Neboit, Papin, Pottier, Puimean-Chieze & Viard, 1978) and radiological inspection tasks (Papin, Metges & Hernandez, 1983) to indicate longer FDs for experienced performers - a finding supported in part by the increased FDs which are observed when extended practice is provided on static tachistoscopic tasks (e.g. Furst, 1971; Schaffer & Gould, 1964; Schroeder, 1969a, 1969b, 1970; Schroeder & Holland, 1968). Similar trends for increased FD with practice in car drivers have been reported (Allen, Schroeder & Ball, 1978), but in the
Research Design Options

OPTION A
Set Search Time: Dependent Measure is Response Accuracy to Display Information.

SUBJECT A

SUBJECT B

(Subject A samples at a faster rate and therefore has shorter FD that Subject B).

OPTION B
Variable Search Time: Dependent Measure is Response Speed.

SUBJECT A

SUBJECT B

(Subject A has the same number of fixations as Subject B but samples the display at a higher rate).

SUBJECT A

SUBJECT B

(Subject A has a different number of fixations to Subject B but samples the display at the same rate).

Figure 14: Dependence and Independence of the measures of number of fixations and mean fixation duration (FD) under conditions where subjects are given a constant time course of display information and are required to respond for accuracy (Option A) or are given the task of responding as rapidly as possible resulting in variable search times (Option B). In the first case the 2 measures of number of fixations and FD are inversely dependent and provide comparable estimates of search rate. In the second case only FD provides a reliable measure of search rate which can be used to compare between Ss or between tasks.
absence, however, of concomitant proficiency-related differences in search rate. This highlights the potential problems in trying to imply search strategy differences between experts and novices on the basis of the direction of practice effects alone.

Obviously then, despite the expectation of longer FD's for experts, to date no clear systematic differences in search rate in ergonomic tasks have been isolated which can be directly attributed to differences in subject proficiency. The existing studies are however, fraught with methodological and paradigmatic limitations and the data base provided by the ergonomic investigations of visual search is not a good one upon which to test the notions of proficiency-related differences in visual search for fast ball sports. Methodologically there appears confusion in the literature regarding the use of the number of fixations as opposed to fixation duration as indicants of search rate (see Premack & Collier, 1966) and there is generally little consideration made of the interdependence and independence of these measures in the design of the search tasks (see Figure 14). In cases where all subjects are presented with a constant duration display, and a dependent measure of response accuracy is used for the task, the visual search measures of the number of fixations and FD are inversely proportional with either measure providing a reliable comparative indication of search rate. When subjects are required to make a visual judgement as rapidly as possible however, and the overall search time consequently varies between subjects, these two measures become no longer identical. In these instances of variable search time (Figure 14), the number of fixations, whilst providing an indication of the number of different locations which need to be sampled
in order to make a judgment, no longer provides a reliable measure of search rate for comparing between subjects or between tasks. Unfortunately many of the ergonomic studies of visual search employ designs which result in variable search times between subjects but report only measures of the number of fixations and not FD in assessing search rate.

Comparison of findings across the different ergonomic studies of visual search is made difficult not only because of differences in the search rate parameters reported but also because of differences between studies in the instructional sets imposed (in terms of speed or accuracy requirements), differences in the criteria used to define a fixation and differences in the nature of the specific display information provided, be it static or dynamic. As visual search appears to be very display specific (Cohen, 1978b) further examination of potential proficiency-related differences in the visual search strategies of expert and novice fast ball sport performers necessitates the use of sports performers and sport-specific stimuli rather than reliance upon this recipient knowledge from ergonomics.

2. Sport Task Literature

Despite the great hope held for eye movement recording as an approach to understanding perceptual processes in sport (Rothstein 1977a), applications of eye movement recording to motor behaviour, and sports problem situations specifically, did not emerge until the mid-1970's (e.g. with Bard, Fleury & Carrière, 1975; Haywood, 1977; Williams
& Helfrich, 1977), some 20 to 30 years after these techniques had been used in ergonomic settings (e.g. Milton, 1952; Tiffin & Bromer, 1943). A growing number of studies in the 1980's have however addressed the role of visual search in sport performance, with the majority of these pertinent studies arising in non-English sources, most especially in the French-Canadian works of Bard and Fleury (e.g. Bard & Fleury, 1976a, 1976b, 1981; Bard, Fleury, Carrière & Halle, 1980), the French work of Ripoll (e.g. Ripoll, 1984; Ripoll & Coulibaly, 1985; Ripoll, Papin, Guezennec, Verdy & Philip, 1985; Ripoll, Papin & Simonet, 1983) and the German works of Haase, Neumaier and Ritzdorf (Haase & Mayer, 1978; Neumaier, 1982, 1983; Ritzdorf, 1983). With recent advances in eye movement recording technology there has been a pleasing move toward the use of more ecologically valid field settings for data collection but a number of methodological and interpretative problems persist which weaken current understanding of visual search in sport.

The seminal work on the application of eye movement recording to sport perception problems can be attributed to the oft-published data set of Bard and Fleury (1976a, 1976b, 1976c) derived from the examination of the search patterns of five expert and five novice basketballers. Bard and Fleury presented their subjects with a series of schematic slides depicting offensive positions in basketball to which the subjects were required to make, as rapidly as possible, a verbal response selection (from the four choices of 'shoot', 'dribble', 'pass' or 'stay'). The subject's visual search patterns were recorded whilst performing the task and data regarding the frequency and location of fixations were used, in
conjunction with the decision time, as the dependent variables. No significant differences in decision time were obtained despite the faster mean vocal RT for the expert group but differences in a number of visual search parameters were obtained. Specifically experts were found to fixate more upon significant empty space and the positioning of their team mate's opponent than did novices, indicating differences in pertinence assigned to different sections of the display. Moreover, in line with the earlier observations from inspection tasks by Schoonard, Gould and Miller (1973), experts were seen to require fewer fixations in order to reach response selection decisions and, in the absence of decision time differences, this was interpreted as evidence for slower, and more selective sampling of the environment, by the experts.

Although this study served as an important stimulus in terms of encouraging visual search examinations of sport tasks, and as such has been widely cited in contemporary sport science literature, the study has a number of methodological and interpretive difficulties which warrant elucidation (see also Davids, 1982). Firstly it should be recognized that only a small sample size is used and this may, among other things, explain the failure to obtain significant differences in decision time, despite quite marked differences in the mean values (e.g. cf the larger sample size results reported by Carrière, 1978 on the basis of a similar task; see p. 79). An increased sample size, and the possible achievement of reliable differences in decision time, may result in quite substantial differences in the manner in which both decision time and ocular sampling rate need to be interpreted.
Secondly, and perhaps most importantly, the task used is fraught with problems related to ecological validity. The stimuli presented are only diagrammatic representations of player positions and not slides of 'real' players. This artificially limits the available display information to spatial cues only, removing critical contextual cues which may be given by both opponents and team-mates. The physical matching of each team-mate with his opponent will undoubtably influence the ball carrier's decision in the real game situation, for example, but this information is not available in this task. The use of schematic presentations may also present a bias in favour of the experienced players who, unlike the novices, may have encountered this form of information presentation previously, thus introducing the complexity of possible group differences arising as a consequence of familiarity rather than task proficiency. Further, the static nature of the display presentation through the medium of slides may in itself alter the performer's normal game search patterns, forcing the performers to attend to objects in the display rather than to changing events in order to extract critical information. The fact that responses can be made to static displays much faster than to dynamic ones (Pauwels, 1980) suggests that the use of static displays may possibly alter the subjects dependence on different cues, thus invalidating many of the conclusions drawn. Finally there are questions of ecological validity surrounding the use of an artificially simple response mode, and the reduced attentional and temporal demands of the whole task, which bring the conclusions of this original study under some question.

There are also hidden interpretative problems which are not
addressed in this study, and indeed in many of the subsequent studies. The differences in fixation locations between experts and novices which are implied to demonstrate differences in cue usage for example, may not necessarily indicate differences in focal attention but may rather reflect differences between the groups in capability to extract information through the peripheral retina (Davids, 1982). The restriction of eye movement recording techniques to providing information about foveal vision alone is not considered and, as in all the other studies of visual search in sport, the general limitations and assumptions associated with the use of the eye movement recording technique are not discussed. (These factors will be considered in detail in Chapter 4).

The interpretation of differences in sampling rate between experts and novices may also be an artifact of the paradigm used arising as a consequence of both response speed and accuracy being allowed to co-vary. As subjects are required to respond as rapidly as possible the time taken to view each of the slides varies between subjects, and between the skill groups, and consequently the number of fixations parameter can not provide a reliable indication of search rate (see Figure 14). All that can be generated is the observation that experts need fewer fixations in order to make a response selection decision but even this may be merely due to a different willingness by the two groups to trade-off speed and accuracy. The respective decision times of the two groups, for example, may be achieved with substantially different error rates, but this is difficult to determine when the accuracy data is not reported.
TABLE 3

Visual search rates from Bard, Fleury & Carrière (1975) compared using the number of fixations (NF) and mean fixation duration (FD).

(Data is based on information provided by Bard & Fleury (1981) in Table 4.1 and FDs were estimated by dividing decision time by NF)

<table>
<thead>
<tr>
<th>Search Rate Measure</th>
<th>Solution Complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>One Possible Solution</td>
</tr>
<tr>
<td>Mean Number of Fixations</td>
<td>Experts</td>
</tr>
<tr>
<td></td>
<td>Novices</td>
</tr>
<tr>
<td>Mean Fixation Duration</td>
<td>Experts</td>
</tr>
<tr>
<td></td>
<td>Novices</td>
</tr>
</tbody>
</table>

Note: The interpretation of the effect of solution complexity upon search rate made by Bard et al depends upon which measure of search rate is used. From the NF parameter it appears that experts sample at a slower rate than novices irrespective of the situation complexity. However, when FD is calculated, the slower search rate for experts appears under the one solution condition only.
When FDs are estimated for this data set (see Table 4) expert players are shown to have slightly longer FDs than novices but the differences are not as pronounced as when the differences in search rate are implied, inappropriately, from the number of fixations. Importantly, use of the number of fixations as opposed to FD as an indicant of search rate under variable decision time conditions, can result in quite conflicting conclusions being drawn, as in the case of the data from Bard, Fleury and Carrière (1975) re-examined in Table 3. Severe caution is therefore needed in implying search rate differences in the absence of FD data.

A number of the problems of ecological validity evident in this early study have been subsequently alleviated through replacing the static presentation of stimuli via slides with the use of dynamic film displays. In a later study Bard, Fleury, Carrière and Hallé (1980) recorded the search patterns of four experienced and three inexperienced gymnastics judges as they observed a video-tape of a series of gymnastic routines. As with the earlier study it was demonstrated that experts and novices fixate upon different display areas, and hence utilize different cues in arriving at their response selections (in this case routine scores) and this was evident mainly in a greater upper body focus by the expert judges. As previously the expert judges also used fewer mean fixations than did the less experienced judges but the differences failed to reach significance levels, presumably because of the small sample size, the high individual variability (especially within the less experienced group) and the absence of a control group who were true task
TABLE 4
Summary of Visual Search Studies Comparing Expert & Novice Sport Performers

<table>
<thead>
<tr>
<th>STUDY</th>
<th>TASK</th>
<th>SETTING</th>
<th>SUBJECTS</th>
<th>EXPERT-NOVICE DIFFERENCES</th>
<th>FIXATION DURATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bard &amp; Fleury (1976 a &amp; b, 1978)</td>
<td>response selection from schematic diagrams of basketball offences</td>
<td>lab setting; static stimuli</td>
<td>5 expert basketballers; 5 novice basketballers</td>
<td>more fixations to areas of open court space by experts</td>
<td>estimated fixations durations:</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>experts = 293 msec</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>novices = 252 msec</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>expert judges have more fixations on the upper part of the body, novice judges concentrate more on the legs.</td>
<td></td>
</tr>
<tr>
<td>Bard, Fleury, Carrière &amp; Halle (1980)</td>
<td>judgement of optional &amp; compulsory gymnastic routines</td>
<td>lab setting; dynamic stimuli</td>
<td>4 nationally certified judges; 3 uncertified judges</td>
<td>expert judges have more fixations on the upper part of the body, novice judges concentrate more on the legs.</td>
<td>expert judges have 27% fewer fixations; FD not given and cannot be estimated because of lack of information on trial duration</td>
</tr>
<tr>
<td>Neumaier (1982)</td>
<td>observation of a floor exercise in gymnastics</td>
<td>lab setting; dynamic stimuli</td>
<td>proficient gymnasts &amp; non-gymnasts (n=128)</td>
<td>expert gymnasts have more fixations on the middle of the body close to the axis of rotation; novices pay more attention to peripheral sectors of the body</td>
<td></td>
</tr>
<tr>
<td>Bard &amp; Fleury (1981)</td>
<td>ice hockey goal-keeping</td>
<td>field setting</td>
<td>?</td>
<td>experts, regardless of shot type, fixate upon the stick (65%) more than the puck (35%). Novices' fixations on these two areas varied according to the type of shot executed by the opponent.</td>
<td></td>
</tr>
<tr>
<td>STUDY</td>
<td>TASK</td>
<td>SETTING</td>
<td>SUBJECTS</td>
<td>EXPERT-NOVICE DIFFERENCES</td>
<td>FIXATION LOCATIONS</td>
</tr>
<tr>
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<tr>
<td>Bard, Guézennec &amp; Papin (1981)</td>
<td>training &amp;/or competition fencing</td>
<td>field setting</td>
<td>2 Masters</td>
<td>all groups give greatest priority to the hand guard; Master fencers use the upper arm less than do the other groups</td>
<td></td>
</tr>
<tr>
<td>Haase (1978) &amp; Mayer</td>
<td>decision task based on viewing of stimuli which were either relevant or irrelevant to fencing</td>
<td>lab setting</td>
<td>12 Experts</td>
<td>Experts had longer FDs for relevant stimuli (420 msec v 300 msec) but no differences on either of 2 irrelevant stimuli (450 msec v 400 msec and 510 msec v 400 msec).</td>
<td></td>
</tr>
<tr>
<td>Ripoll, Bard, Paillard &amp; Grosgeorge (1982)</td>
<td>basketball shooting task with either (1) the ball commencing in the hands, or (2) on receipt of the ball. 120° turn to the left in order to shoot</td>
<td>contrived field setting</td>
<td>5 experienced basketballers; 5 novice PE students</td>
<td>time to fixate the eyes on the target prior to release was longer, but not significantly so, for novices (221 msec v 104 msec) - these are, however, not true PD indicants.</td>
<td></td>
</tr>
</tbody>
</table>

* a – estimates of PD derived from $\frac{DT}{NP}$
novices. In this case, if a constant viewing time is presumed for all subjects (see Figure 14), the differences in the number of fixations observed should also be truly indicative of a lower search rate for the experts.

Subsequent work by Vickers (1984, 1985) using slides of World Class gymnasts and a large sample size (n = 30), has also revealed differences in the specific cue usage of expert and novice gymnasts although parameters relating to search rate were not examined. Similarly Neumaier (1982), although also not examining search rate, revealed differences in the manner in which proficient gymnasts and non-gymnasts observe a gymnastic routine (a floor exercise). In this study experts were found to make most fixations around the middle of the gymnast's body close to the axis of rotation (points of high biomechanical pertinence) whereas novices' attention was attracted more frequently to peripheral sectors of the moving body.

More recent visual search analyses by Bard and her associates have continued the evolution of more ecologically valid experimentation by pursuing the recording of eye movement behaviour within field rather than laboratory settings. Although the restrictions in eye movement technology limit field recording to tasks in which the performer is relatively stationary this progression to field testing is desirable in view of the possible alterations in search strategy which may occur from the laboratory to the 'real-world' setting (Cohen, 1978b).

Bard and Fleury (1981) report data drawn from the recording of the eye movements of ice hockey goalkeepers faced with the task of blocking
either slap shots or sweep shots executed by an opponent. Although search rate differences were again not examined, differences in the visual cues used by expert and novice goalkeepers were apparent from the analysis of fixation locations. Expert performers maintained consistent fixation location distributions (approximately 65% of fixations on the stick and 35% on the puck) regardless of the shot type whereas the fixations of the novices varied considerably dependent on the shot type being used by the offensive player. These alterations in fixation location by the novices may be objective evidence of their selective attention being drawn to irrelevant or less relevant cue sources.

Examination of a comparable goal-keeping task, goal-keeping in soccer, was also conducted by Tyldesley, Bootsma and Bomhoff (1982), through the use of slide presentations of the kicking actions preceding ball flight. Although the group sizes (n = 8) were considered too small to draw comparison between experts and novices, some systematic effects on the scan patterns were noted according to the task instructions. When the subjects were required to make judgment on both the height and lateral direction of the forthcoming shot at least two fixations on the slide material were required - the first being directed usually to the hip region and the second primarily to the opponent's shoulder or head. If subjects were required to anticipate the lateral direction only, often only one fixation was necessary and this was most frequently directed to the lower leg or striking foot indicating this distal segment as the most

20. Interestingly this is a much larger sample size than many of the studies in the Bard series (see Table 4) which draw expert-novice comparisons.
pertinent source of directional information.

Bard, Guezennec and Papin (1981) have also examined, through a small sample of two masters, four experts and four novices, the visual search patterns of competitive fencers, both in lessons and in duelling situations. For all skill groups the most important source of information appeared to be the opponent's hand guard and the majority of fixation location changes were seen to involve saccades shifting the focal attention between the hand guard and its neighbouring elements (the forearm and the upper arm). Higher search rates were evident for all fencers as they moved from the training situation to the temporal stress of the competitive situation. Lower FDS, and hence higher search rates, were apparent for the superior performers in this competitive situation. Despite the conclusions drawn in this paper, these data appear to run contrary to the earlier Bard and Fleury (1976a) and Bard et al. (1980) data, and the contention of lower search rates for experts.

Earlier comparative work on fencing is also available in the research of Haase and Mayer (1978) who used a much larger sample (12 experts and 13 novices) but a less ecologically valid task than that reported by Bard, Guezennec and Papin. Using a visual RT task with stimuli either relevant or irrelevant to fencing, Haase and Mayer observed significantly longer FD for expert fencers, but on the fencing-relevant stimuli only. The results obtained therefore confirm the sport-specific influence of expertise upon visual search strategy as observed previously in behavioural measures such as decision time (e.g. Ryan & Lakie, cited in Ryan 1969; Tyldesley et al., 1982) and structure
recognition (e.g. Allard, Graham & Paarsalu, 1980). Differences in
search strategy between experts and novices therefore appear to reflect
not general visual-perceptual differences but rather differences which are
due to sport-specific experience and expertise. Moreover, in contrast to
Bard, Guezzeneç and Papin (1981), the observation of longer FDs for
experts by Haase and Mayer is in keeping with the expectation of lower
search rates for experts (attributable to their lower information
processing load) and is compatible with the earlier Bard and Fleury
(1976a) and Bard et. al. (1980) findings.

Recent foreign studies are also now available concerned visual search
activity in volleyball (Neumaier, 1983; Ripoll & Coulibaly, 1985) and in
some racquet sport situations (Ripoll & Fkeurance, 1985; Ritzdorf, 1983).
Neumaier (1983), for example, in monitoring the search patterns of
defensive players in volleyball has observed a preponderance of fixations
upon the striking arm and shoulder joint of the opposing spiker rather
than on the ball at contact and his data like Bard and Fleury (1981)'s,
demonstrates almost a total absence of lower body fixations. Ritzdorf
(1983), in the racquet sport of tennis, has reported, from a large sample
of 112 players drawn from 4 different proficiency levels, a wide
scattering of ocular fixations by the players across the display
presented by their opponent. At least three different search order
strategies have been reported (i.e. continuing eye movements following
the ball, fixations in the order shoulder-ball-shoulder and fixations in
the order shoulder-shoulder-ball) but data on skill group differences in
these search strategies is difficult to extract.
To date the studies of visual search in sport which have been considered have been concerned with the manner in which the performer perceptually analyzes the environment in order to select an appropriate course of action, what Ripoll, Papin and Simonet (1983) have termed psycho-semantic operations. A recent focus of a series of studies by Ripoll and his associates (Ripoll, 1984; Ripoll, Bard, Paillard & Grosgeorge, 1982; Ripoll, Papin & Simonet, 1983) has been upon the role that visual input plays in the subsequent control and organization of the selected motor action, the so-called psycho-sensory motor operations. Although these studies are a little 'peripheral' to the concerns of the current thesis, the observation of more rapid head/eye alignment by proficient basketballers in a contrived shooting task (Ripoll et. al., 1982) and the observation of large individual differences in the visuo-motor activity of even an apparently homogenous group of elite pistol shooters (Ripoll et. al., 1983, 1985; Ripoll, 1984) serve timely reminders of the possible artificiality of considering group differences in ocular search strategy alone without due consideration of other factors such as concomitant head movements and possible intra-group variability.

In summary then, the available visual search literature in sport, much like the ergonomic literature, contains numerous methodological and paradigmatic difficulties which limit its utility as a base from which to examine selective attention and information-processing notions related to playing expertise. Many of the more influential studies use small sample sizes and are of questionable ecological validity and, almost without exception, alternative explanations to the data explanations advanced are
possible. In particular the role of possible proficiency-related differences in the ability to use peripheral inputs are not considered in assessing visual search performance and there is a general neglect in all the studies cited to consider the limitations and assumptions inherent in the use of the eye movement recording method. There is, nevertheless, ample evidence from the existing eye movement recording studies (see Table 4) to demonstrate qualitative differences in the specific environmental cues focally attended to by experts and novices. These differences in cue usage may reflect differences in pertinence and, in turn, in the quality of information being processed, although a clearer relationship between the specific visual cues used in sport and concomitant anticipatory performance still needs to be established.

Aside from differences in the quality of the information selected for processing, theories of selective attention also predict differences in the respective amounts of information that need to be processed by experts and novices. In theory, experts are expected to process less information because of their earlier recognition of redundancy within the display and the existing behavioural evidence reviewed previously appears to support this notion (see pp. 75-85). As the information-processing load appears to be the principal factor influencing search rate in cognitive tasks (Teichner & Krebs, 1974; Teichner & Mocharnuk, 1979, and as search rate also appears to increase whenever task complexity or temporal stress is added in applied tasks (e.g. Bard et. al., 1981; McDowell & Rockwell, 1978), it is to be expected that within the visual search paradigm expert performers may be able to use a lower search rate than the novices in
processing the information contained within a given perceptual display. The characterization of the expert by the use of a search strategy using fewer fixations, each of longer mean duration, is to be expected, not only because of the lower processing demands believed to be faced by the expert (the 'variable processing rate' hypothesis of Teichner and Krebs, 1974), but also because of the expected greater capability of experts to extract information via peripheral vision, without the necessity for foveation changes (Davids, 1984). Furthermore the use of a search strategy in which the number of fixations is reduced is also in line with the expected reduction in the number of cues needed by the experts to perceptually construct the familiar display of their specific sport (the 'perceptual automatizing' hypothesis of Furst, 1971) and is an efficient one in terms of maximizing the possible time for information extraction (during fixations) and minimizing the inactive processing time associated with saccadic movements.

The search rate of a subject can be potentially altered in one of two ways - either by altering the FD or perhaps by altering the time spent in making saccadic movements. Although there is some evidence derived from simple tachistoscopic studies to indicate greater saccadic eye movement speed for successful performers in baseball batting tasks (Williams & Helfrich, 1977) by far the greatest potential for modulating overall search rate comes through alteration of the FD. In the limited evidence on FD which is available from examinations of fast ball sports (see Table 4) there is some indication of lower search rates for experts (reflected in higher FD), indicating perhaps their greater awareness of the location of pertinent cues and their consequently lower information processing
requirements. Although some anecdotal evidence exists supporting these proficiency-related differences in visual search strategy (e.g. Sandu, 1982 reports skilled volleyballers "zooming" to cues whereas novices rather "scan" to locate pertinent cues) the existing empirical evidence for such differences is far from unequivocal (e.g. contrast the findings of the studies by Haase and Mayer, 1978 and Bard et. al., 1981 on fencing). Clearly, to date, potential search rate differences between expert and novice performers have been inadequately examined in 'real-world' settings.

**V SUMMARY**

In this chapter the available literature regarding selective attention and visual search in fast ball sports has been reviewed, especially from the perspective of potential differences between the performance of the expert and the novice. Effective selective attention is necessary in fast ball sports to reduce the informational complexity of the environment to manageable amounts and this is achieved, during the available VT, by giving optimal attention to task-relevant cues only and by recognizing structure, and hence redundancy, in the perceptual display. Contemporary theories of selective attention (e.g. Norman's, 1968, 1969 theory) suggest that selection of pertinent cues proceeds through a matching in short term memory of current sensory input with items of predicted pertinence retrieved from memorial representations of the performer's prior task experiences.

This view of the selective attention process leads to certain
postulations regarding the source of selective attention differences between experts and novices, and there is some evidence available from sport-specific studies to support a number of these postulates. Specifically it appears that experts have superior anticipatory capabilities to novices due to an ability to recognize situation structure and redundancy much earlier than can the novices. Further, there is some evidence to indicate that experts bring to new situations more appropriate expectations regarding event probabilities in the ball sport setting, and hence make more appropriate assignments of pertinence than do novices. These differences in visual selective attention apparent in behavioural studies, are also supported by some evidence from eye movement recording in sport-specific situations which indicates the use of different sources of information and perhaps also different (lower) search rates by the expert performers. This latter difference, for which only scant evidence is available, is taken as indicative of possible differences in the amount of information which has to be processed, and uncertainty which needs to be resolved, by the two skill groups.

Although a number of the predictions arising from visual selective attention theory have been supported by sport-specific research, the tests of these predictions which have been conducted have been generally non-systematic (the so-called "shot-gun" approach; Ryan, 1968) and fraught with methodological flaws. Specifically there has been an absence of a systematic approach and/or 'master plan' toward examining all of the predictions of selective attention theory (the majority of studies are usually one-off attempts searching for 'single discriminatory variables)
and much of the research has taken place without consideration of the essential need to preserve ecological validity in the testing environment. Many influential studies in the area of sport perception have given, unfortunately, minimal regard to the need to retain display integrity through the use of dynamic sport-specific stimuli and the concomitant need to preserve realistic temporal and attentional demands comparable to those existing in the actual performance setting. Throughout, large implications concerning proficiency-related differences in perception have been made on the basis of very small data sets, often without acceptable control populations.

The dominant methodologies used to date in the study of sport perception (most notably the film occlusion technique and the eye movement recording technique) have, furthermore, been applied to sport problem situations without any attempt to establish the validity and reliability of the measures used (see Safrit, 1977) or without any consideration of the assumptions and limitations of using such methods. Differences in specific cue usage between experts and novices, for example, have been established only through differences in fixation location observed from visual search studies. Consideration has not been given to the possibility of these differences being due to differences in peripheral visual usage - a possibility which can not be examined within the eye movement recording method alone. Additionally there has been, aside perhaps from the study by Tyldesley et. al. (1982), little attempt to incorporate these two dominant methodologies to relate visual search differences directly to differences in anticipatory performance,
thereby throwing many of the existing tentative conclusions regarding expertise-related differences in perceptual strategy in sport into question.

In view of these quite severe limitations in the existing research base it is the purpose of this thesis to examine, in a systematic manner, the predictions made from selective attention theory regarding differences in the perceptual strategies of experts and novices in fast ball sports. Logically, therefore, in view of the perceived limitations in the current research methods and knowledge base, the first step towards such a systematic examination of the perceptual strategies in sport must be with the selection and/or development of a research methodology which allows perceptual strategies, especially with respect to specific cue usage, to be reliably determined. Chapter 4 addresses this selection problem.
CHAPTER 4

PARADIGMS FOR EXAMINING PERCEPTUAL STRATEGIES IN FAST BALL SPORTS

A sound methodological paradigm for assessing perceptual strategies in 'real-world' motor skills is essential in terms of answering both important theoretical and applied questions related to visual selective attention. In a theoretical sense a sound methodology for assessing perceptual strategies is necessary in order to test predictions generated from theories of selective attention and visual search regarding potential differences in the perceptual strategies of experts and novices. Similarly, a means of reliably assessing perceptual strategies in sport may be of applied use in deriving specific information, of practical importance, regarding the source of the most pertinent information for any particular fast ball sport or comparable 'open'-skill task.

Over twenty years Knapp (1963, p. 156), whilst observing that 'the outstanding games player seems to react to situations much sooner than the average player' and postulating that 'this is probably due in part to his identification of cues which appear early rather than having to wait for the later and more obvious ones', also noted with some regret that

Much more knowledge is needed of the signals in any particular game to which skilled players react. Very little work has been done on identifying the important cues and this seems a rich field for the extension of skill teaching in the future.

Unfortunately these comments regarding the state of research knowledge on the perceptual nature of sport skill still seem quite pertinent today and relatively minor advances appear to have been made with respect to procedures for identifying the important cues within specific sports. Specifically, therefore, within the objectives of this thesis, and in view of the current methodological shortcomings in terms of procedures for assessing specific cue usage in 'open' motor skills, it is necessary to develop a research paradigm which allows valid and reliable assessment of both

(a) individual and proficiency-related differences in the time at which critical cues are extracted and (b) individual and proficiency-related differences in the source of critical information.

The purpose of this chapter is therefore to critically assess the advantages and disadvantages of a number of existing paradigms for determining cue usage and from this assessment, and from assessment of the contribution of each of these paradigms to the current knowledge base, develop a new, composite paradigm through which perceptual strategies in sport can be systematically and reliably examined.
Self-Report or Verbalization Techniques

The simplest approach to determining what specific cues different performers use in sport tasks may be through direct questioning techniques i.e. by having the subjects verbalize or self-report upon their cue usage immediately following task performance. This technique is frequently applied in an attempt to examine the cognitive processes operative in problem-solving tasks (e.g. see Chase & Simon, 1973a) and in examining the cognitions of human operators within the workplace (e.g. see Edwards & Lees, 1974; Leplat & Hoc, 1981). A limited number of examples of the application of post-hoc verbalization techniques to the assessment of selective attention in sport settings are also available. Sandhu (1982), for example, reports data on the selective attention of a sample of national level volleyball players using interview techniques designed to assess the selective orientation of the players to different aspects of the visual display of the opposing team.

The verbalization technique offers a number of advantages for assessing perceptual strategies, not the least of which relates to its ease of implementation. The data obtained through verbalizations are performer-specific and are therefore possibly directly indicative of the individual performer's self-beliefs and cognitions and indeed there is some evidence, at least from simple static tasks, to implicate a reasonably direct relationship between visual search activity and the performer's subjective estimates regarding the location of critical display information (Kundel, 1974; Pollack & Spence, 1968; Schissler, 1969). There are, however, also a number of quite substantial
difficulties associated with the use of these self-report techniques which necessitate ultimately, the selection of more objective approaches to the assessment of perceptual strategies in sport.

One of the major disadvantages with the verbalization technique is that the expert performer may conceivably reach such a stage of skill automation that he/she becomes unaware of the specific cues being used in making perceptual judgments. As Whiting (1975, p. 27) notes of the experienced player

He 'knows' what to do and when to do it, but it would appear that he is often not conscious of having made a decision.

In this case where cue extraction occurs below the level of cognitive consciousness or awareness even the use of hypnotic techniques may not aid in discerning actual cue usage. The verbal reports of performers are subject to expectancy effects and may be made on the basis of inferences from the observed movement outcomes rather than from direct knowledge of the underlying cognitive processes used in producing these particular outcomes (Leplat & Hoc, 1981; Nisbett & Wilson, 1977). Experienced players, for instance, may expect that they use specific cues merely because of the skilful movement outcomes they achieve or because they have been given coaching emphasis towards particular cue sources when in fact their perceptual strategies may involve the use of cues drawn from quite different sources. There is anecdotal evidence of elite fast ball sport performers denying their use of cues other than those arising from ball flight or of tennis players reporting seeing the ball strike the racquet strings when visual contact has been clearly lost much
earlier (e.g. see Stein & Slatt, 1981), which exemplify some of these difficulties associated with assessing perceptual strategies through verbal reports alone. Obviously a more objective procedure for determining perceptual strategies is required and the first major issue in the selection of an objective test is with the determination of the most appropriate testing environment, be it either the field or the laboratory setting.

I: TEST ENVIRONMENT SELECTION: FIELD V'S LABORATORY APPROACHES

Applied research in 'open' motor skills offers two alternative research settings and approaches - the so-called 'field' and 'laboratory' approaches (Martens, 1975, pp. 15-18). The field approach is based upon observation of the human performer in his or her actual performance setting with the performer essentially uninfluenced by experimenter intervention. The laboratory approach, on the other hand, involves the removal of the performer from the real setting into a simulated setting where stricter control over salient situational variables can be exerted by the experimenter.

A persistent theme in recent sport psychology research, arising largely from Neisser's (1976) work in visual perception, has been with the importance of maintaining ecological validity within the applied research paradigm (e.g. see Davids, 1984; Fujita, 1982; Salmela, 1981, pp. 10-11; Tyldesley, 1981; Whiting, 1982; Whitson, 1978). A number of recent calls have been made for the greater use of field-based testing (e.g. Martens, 1979) because of the perceived advantage of testing in
this environment for the preservation of ecological validity and the preservation of critical situation-specific cues. Unfortunately field-based research on 'open' motor skills is quite infrequent largely because of the difficulties inherent in achieving satisfactory experimental control and replicability within this setting. Arguably no two instances in any 'open' motor skill are ever exactly the same and this obviously presents difficulties to the researcher who is concerned with systematically examining the response of different performers to the same environmental display.

Such problems in field testing account for the predominance of laboratory examinations of perceptual skills in sport. Laboratory examinations typically proceed through simulation of the perceptual display of the 'real' setting through the use of media such as film or videotape; the obvious advantage of such simulation being that it provides a means of introducing experimental control and replicability to a performance domain which is, by definition, highly variable. Film simulation of the 'real-world' display also provides the advantage of allowing for the simultaneous testing of a number of subjects - an advantage which, although of secondary importance, is of considerable value to the experimenter (Cedar, 1977, p. 574).

The trade-off in attaining this experimental control is an unavoidable reduction in some aspects of ecological validity. Cameras capturing display information onto film media are incapable of fully simulating normal human vision and this results in a subsequent visual field representation which is not only reduced from three dimensions to
two, but which is also reduced in terms of angular range. The reduction of the normal three-dimensional display to a two-dimensional one may lead to the loss of stereoptic cues for judging distance and depth, although this limitation may not be a severe one over normal viewing distances as many of the critical cues for depth perception may be monocular (e.g. see Kerr, 1982, pp. 178-182; Sage, 1984, pp. 135-141). Nevertheless available evidence comparing depth judgments made in field and laboratory settings (Day, 1980) does indicate an increase in depth error with the use of film simulation, implicating film simulation as disruptive to the depth perception cues normally available within the 'real' display. The use of standard viewing screens in film simulation studies of sport similarly results in the presentation of a stimulus field size which is less than that encountered in the field setting (especially if consideration of the normal subject-to-image distance or of the subject's normal viewing position is not made) and this reduction in functional visual field size may act to effectively decrease the task difficulty and task demands facing the subject (Davids, 1984)22. Further losses of ecological validity may arise from the disruption to less apparent, but nevertheless important cues such as the auditory cues associated with the display - cues which may play an important role in decision-making in the intact situation (Cobner, 1981; Docherty, 1973; Robb, 1972, pp. 61).

22. In commercially available flying or driving simulators display information is often presented over a realistic viewing range (approximately 120° in flight simulators) but this has not been done in laboratory sport studies where the viewing angles within which stimuli may arise are significantly reduced from the 'real' setting.
These film-based laboratory approaches also usually entail some simplification of the task as a whole and disruption to the task as a single entity. Use of film to reproduce display aspects is typically associated with a perceptual research emphasis and this may force a corresponding de-emphasis of the motor or output aspects of the skill. Although this de-emphasis of the motor component is necessary in the majority of cases to reduce additional between-subject variability arising from the motor component, what may result is the reduction of what is usually a complex response to a very simplified action. It would appear then that caution is required in using these laboratory approaches to ensure that ecological validity is maintained for not only the perceptual aspect of the skill, but also for the motor aspect (Whiting, 1982).

Although there is some evidence from ergonomic settings, especially from driving tasks, showing similar subject responses to film displays as to the 'real' (field) display (Evans, 1970; Laye & Nebolt, 1984; Stone & Ellingstead, 1975; Torf & Duckstein, 1966), and therefore supporting the validity of laboratory testing methods, some conflicting evidence also exists (e.g. Cohen, 1978b) demonstrating differences in subject response strategies from the laboratory to the field setting. The selection of the testing environment and the search for the optimal methodology for examining perceptual strategies appears consequently to necessitate some inevitable trade-off between the demands of minimal artificiality (as provided by the field setting) and maximal control (as provided by the laboratory setting) (Bachrach, 1981, pp. 93-107). Frequently, therefore, in applied research some compromise designs are adopted (e.g. see the
operational analysis approach of Whiting and his co-workers; Whiting, 1982) which attempt to preserve ecological validity in essentially controlled laboratory settings. This also appears to be the most logical tack upon which to pursue the applied problems of interest in this thesis.

In the sections which follow the field and laboratory techniques currently available for assessing perceptual strategies in sport 23 will be considered in terms of their applicability, advantages and disadvantages, limitations and assumptions and, on the basis of this assessment, an experimental paradigm will be proposed which attempts to compromise these conflicting concerns of ecological validity and experimental control.

II: FIELD-BASED APPROACHES

Through the use of phase-lock cinematography or split-screen dual-camera video recording, it is possible in the field setting of fast ball sports to obtain a simultaneous record of events occurring in the action of both performers, or both sets of performers, without constraining the action of the performers in any way. Records of this type may be utilized to determine the precise time constraints facing the performer.

23. In many cases traditional field-laboratory distinctions between techniques are somewhat arbitrary, as with technological advances, many laboratory methods (e.g. eye movement recording) are becoming viable in field settings. In this review these techniques are considered under the heading of laboratory techniques - this being the test environment in which they were originally developed and in which they have been utilized with greatest frequency.
and this information, in turn, used to implicate potentially useful, and useless, cue sources. The premise of this particular field approach is that if exact time constraints can be determined, estimation can also be made of the point in time at which functional cue extraction is no longer possible. As has been seen in the earlier chapters approaches of this type have been utilized to discuss the time constraints imposed on decision-making, and as evidence for the importance of anticipation, in a wide range of fast ball sports (Abernethy, 1981; Drouin & Larivière, 1974; Glencross & Cibich, 1977; Hay, 1973, p. 210-212; Miller & Shay, 1964; Whiting, 1969; Williams & MacFarlane, 1975). Such approaches are usually based upon an operational model which views the human performer as an essentially linear and serial processor of information. (Refer again to Figure 3).

In the field setting the temporal components of MT and the total time available (TT) may be determined directly from the cinematographic record whilst the latency between the completion of response selection and the commencement of the response (LT) is estimated from laboratory simple reaction time (SRT) measures. Viewing time (VT) can then be seen to be the period in which cues are extracted and then used in the response selection process and this component can be estimated from the difference between TT and the sum of SRT and MT. (See pages 34-35).

The most valuable aspect of this approach is that it allows some estimation to be made of when cue extraction may cease (i.e. the location of the end of the VT) although it does not provide any direct evidence as to what specific cues are used. The procedure does, however, allow
implications to be made concerning what cues arrive too late for usage in response selection, particularly for skills which involve multi-segmental responses. As was observed earlier in Figure 4 for example, the application of this methodology to the study of cricket batting can allow demonstration of the fact that cues arising from ball flight cannot be used in determining foot placement but are available to modify the bat swing (Abernethy, 1984). Similar application of this approach to studying perceptual processes in tennis (Hennemann & Keller, 1983) and squash (Howarth et al., 1984) are also now available.

Clearly this field approach to assessing perceptual strategies in sport is limited by the validity of the underlying operational model, especially in terms of its assumptions regarding the independent and serial nature of the proposed component times and in terms of its indirect estimation of the duration of the response organization and initiation processes. Further, in a functional sense, this particular approach whilst allowing implications regarding the time of critical cue availability provides no means of isolating the spatial location of critical cues and therefore is limited in terms of providing a full description of the perceptual strategies of any given subject.

Given these limitations in the field approaches it would appear that utilization of a laboratory approach may be necessary at this stage. Field-based procedures, nevertheless, still have a very important role to play ultimately in the determination of perceptual strategies in sport and ideally in the long term investigation of cue usage in 'open' skills replication of consistent laboratory findings needs to be established in
the actual performance setting. At this stage however, progression from laboratory to field research, rather than the reverse approach, appears logical.

III: LABORATORY-BASED APPROACHES

Laboratory approaches generally share in common the use of film to simulate the perceptual display. What varies between approaches is the response modes which are selected, the dependent measures which are utilized and the analysis procedures which are adopted. In the section which follows three laboratory approaches for use with film displays (viz. the signal-detection approach, the film occlusion approach and the eye movement recording approach) will be examined in terms of their applications, advantages, assumptions and limitations and in each case a potential paradigm for the study of perceptual strategies in sport will be proposed.

1. The Signal-Detection Approach
(a) Applications

As the name implies, signal-detection theory grew originally out of a need to explain the variable capabilities of human performers to detect the presence or absence of regulatory stimuli (the signals) from within ongoing non-regulatory input (noise). Since its original conception in the mid-1950’s (Swets, 1959; Swets, Tanner & Birdsall, 1961; Tanner & Swets, 1954) signal-detection theory has been applied not only to detection but also to a wide range of other processes. Within the limited range of perceptual-motor skills research, for example, instances
Figure 15: The statistical basis of signal-detection theory
of application of the signal-detection approach to comparison (Cox & Hawkins, 1976), recognition (Swennson, 1980), decision (Bisseret, 1981; Jagacinski, Isaac & Burke, 1977; Newell, 1974a) and output (Jagacinski, Newell & Isaac, 1979) processes are readily apparent, in addition to the applied analyses of detection processes (e.g. Colquhoun, 1967; Cox, 1984; Geyer & Perry, 1982). Arguably the theory underlying this approach has been applied in many cases without sufficient regard for the assumptions and limitations within the original model (see especially Long & Waag, 1981).

(b) **Assumptions and Limitations**

Signal-detection theory is based around a description of the relationship between two hypothetically normally distributed samples of signals and noise (Figure 15) with the operator's (performer's) decision in any instant regarding the presence or absence of a signal being dependent upon (a) the a priori cut-off point selected on the basis of signal probability, and (b) the system sensitivity (d') reflected in the displacement of the distribution means.

There are two basic statistical assumptions underlying signal-detection theory and these are:

1. that the two distributions that the performer selects between are normally distributed and,
2. that these two distributions also display equal variance (Pastore & Scheirer, 1976).
Procedures are available to test these assumptions in stationary environments (see Swets, Tanner & Birdsall, 1961, for example) but it needs to be noted that these same Bayesian procedures cannot be strictly applied to dynamic situations such as those encountered in 'open' motor skills (Edwards, 1962).

The major criticisms of the application of the signal-detection approach to perceptual research are, however, not so much statistical as interpretative. Cohen and Christensen (1970), for example, argue that the very statistical nature of signal-detection theory makes it an inappropriate procedure for investigating psychological phenomena; the human performer, they observe, very rarely makes responses compatible with strict mathematical logic. Broadbent (1971) extends this criticism to question some of the assumptions in the underlying framework of signal-detection theory. In particular, Broadbent questions whether it is acceptable to arrange the observer's perceptual input along a single dimension when this input information is undoubtedly perceived and processed in a multi-dimensional manner. Doubt is also cast upon whether the performer is actually aware of the signal probability at any particular instant, and even given the performer's awareness of his/her own likelihood ratio ($\theta$), the advent of rational behaviour cannot necessarily be assumed. The major limitation to the use of the signal-detection approach in the current context would then appear to be that signal-detection theory is based upon the use of objective probabilities which may not necessarily correspond to the subjective estimates of cue probability of which the performer is himself cognizant (Taylor, Lindsay & Forbes, 1967; Whiting, 1979). These limitations aside, the signal-
Figure 16: ROC curves for experienced and novice mine workers on a visual discrimination task (adapted from Bhgnaut, 1979b).
detection approach can still potentially provide some information pertinent to the assessment of cue usage which is not available from other procedures and this fact alone warrants the consideration of a potential signal-detection paradigm for investigating cue usage.

(c) A Potential Signal-Detection Paradigm for Investigating Perceptual Strategies.

There is an apparent absence of any previous applications of the signal-detection approach to the examination of specific perceptual strategies in 'open' motor skills with the closest approximations existing in ergonomic research, such as that by Blignaut (1979b). Blignaut used a signal-detection approach to examine the capability of mine workers of different skill levels to discriminate safe rock formations from potentially hazardous ones. Subjects were presented with a series of stereoscopic slides of different rock formations and their task was to rate rock safety on a five point scale from 'absolutely certain dangerous rock' (1) to 'absolutely certain safe rock' (5). Receiver-Operating Characteristic (ROC) curves were then plotted for each subject to determine individual differences in perceptual capability (see Figure 16).

It would appear that an analogous design could be adapted for examining perceptual strategies in any 'open' motor skill in which the fundamental task is one of discrete two-choice selection, such as the task in racquet sports of determining whether an opponent's stroke is going down the line or cross court. Judgments in cases such as this however, may need to be restricted to one dimension only (e.g.
directional or depth judgment only) because increasing the number of responses required per trial may cause such increases in response time as to impair the maintenance of realistic temporal constraints within the task.

The fact that the design is limited to discrete selection tasks again raises the question of the similarity of discrete laboratory judgments of this sort to the cumulative form of decision-making which is probably more common in fast ball sports. Further, although this signal-detection paradigm offers an alternative approach to examination of skill level differences in visual search and response selection, specific cue usage cannot be directly assessed. The advantage this paradigm does offer, however, is that it allows subjects to rate their judgmental certainty and to this end the signal-detection approach may well be of greatest value when used, not individually, but rather in combination with the other more direct cue assessment procedures of film occlusion and eye movement recording.

2. The Film Occlusion Approach
(a) Applications

In the occlusion techniques the appropriate environmental display is filmed from the performer's perspective and then this film is shown back to the subjects using a repeated-trials design with the subject being required to report either perceptual judgments (e.g. 'where will the ball land?') or response-selection decisions (e.g. 'what stroke should be played?'). The film shown to the subjects can then be occluded at
various time intervals to determine the importance of given input sequences of the display to the achievement of final decision-making.

This occlusion procedure has been used quite extensively in fast ball sports to demonstrate that advance cues (i.e. cues arising prior to ball flight) provide much task relevant information (Abernethy & Russell, 1984; Enberg, 1968; Isaacs & Finch, 1983 Jones & Miles, 1978; Parick & Spurgeon, 1978; Salmela & Fiorito, 1979; Soullière & Salmela, 1982) with subjects being able to produce response accuracies well in excess of chance level even in the complete absence of ball flight information. Field analogues of this procedure by Snyder (1969) and Day (1980) which have utilized remote controlled visors to occlude vision have resulted in essentially similar conclusions being drawn. Expert performers appear to be more capable of utilizing this advance information than novice performers, with the differentiation between skill groups being most apparent when the occlusion point is made early in the event sequence (Jones & Miles, 1978).

(b) Assumptions and Limitations

In the majority of cases where the occlusion points are determined by the experimenter, and are hence external to the subject, it is necessary to assume that the view of the display available to the subject corresponds meaningfully to the time normally available for the performer to extract the cues necessary for response selection. However, if the subjects are allowed to control the duration of their own viewing time by requiring them to make some time-constrained response to the film display
(see Abernethy & Russell, 1984) this assumption may not be necessary although difficulties may then arise in controlling individual differences in speed-accuracy tradeoff effects. Further, it should also be recognized that the subject's performance under any temporal occlusion condition is not directly related to the occlusion time per se but rather to the total time course of the available visual information -- i.e. the stimulus duration plus the duration of iconic persistence (for a discussion see Sharp, 1978). Assumptions that iconic persistence remains constant both between different temporal occlusion conditions and between the experimental condition and the real performance setting are therefore inherent in the film occlusions approaches unless some form of visual mask is provided subsequent to the display presentation to prevent direct inspection of the iconic image (Fleury, Bard & Carrière, 1982; Neisser, 1967). Similarly, as it may be possible for subjects to hold visual information for delayed processing in laboratory tasks but not in field tasks, it is essential that immediate response selection decisions are enforced in the laboratory situation. Realistic assessment of cue usage from laboratory tasks is only possible if ecologically valid time constraints are maintained (Davids, 1982).

(c) Potential Occlusion Paradigms for Investigating Perceptual Strategies

(i) Temporal Occlusion

Although the temporal occlusion procedure has not, to date, been used as a direct means of implying patterns of cue usage it would appear to provide that potential. Decrements in response accuracy resulting from the occlusion of a specified time period can be interpreted with respect to the importance of the events which have been occluded. The
Figure 17: Hypothetical data to fit a temporal occlusion paradigm.
occlusion of a time period which contains critical cue sources should be associated with a disproportionate decrement in response accuracy in comparison to other equal time periods. In the hypothetical result shown in Figure 17, for example, one could interpret that the expert subject was utilizing advance cues arising some 0-50 msec. prior to contact whereas the novice subject appears to be utilizing later cues arising from the first 50 msecs. of ball flight.

The technique in this state obviously still only allows a time period of critical cue extraction to be isolated and does not allow the location of the critical cue sources to be specified. Clearly this approach will be most appropriate if the skill under investigation contains a single time period when cue pertinence is particularly high. However, one might suspect in many fast ball sports that the critical information may be accumulated over the total duration of the action rather than extracted in a single instance. To alleviate at least some of these concerns with temporal occlusion procedures, an alternative occlusion procedure, in which specific cue sources and events rather than time periods are the basic units of occlusion, warrants consideration.

(ii) Spatial or Event Occlusion

Although there are no prior examples of what could be termed spatial or event occlusion in the literature the concept of selective cue occlusion would appear to have potential as a means for determining, or at least confirming, cue usage. The logic with this approach is to present the subjects with a consistent time course of events in all
Figure 18: Hypothetical data to fit an event (spatial) occlusion paradigm. In this example cue 1 is not important to either skill group, cue 2 is important to experts alone, cue 3 is highly important to both groups, whereas cue 4 is more important to the novice group than to the expert.
trials and to selectively occlude specific cue sources for the complete
duration of each trial. This occlusion can be induced either through the
use of an electronic filter at the time of filming or through later
adhesion of opaque mats directly onto the developed film surface. In
both cases a control condition is necessary in which a known irrelevant
cue is occluded throughout the trial duration to compensate for any
possible compounding effect arising from the film disruption and
subsequent subject distraction. As with the temporal occlusion procedure
the cue source(s) whose removal causes the greatest response accuracy
decrement can be implied to be the most important (see Figure 18).

(iii) **Spatial x Temporal Occlusion**

Logically both the accessibility of a cue and the time at which it
becomes available will influence the perceptual strategy adopted by a
performer and this implies a need to integrate both these temporal and
spatial occlusion procedures. Results achieved from the independent
usage of the two procedures could be used to develop a 'spatial x
temporal' occlusion procedure with the assumption again being that the
'cue x time' occlusion combination which produces maximal response
accuracy decrement is that which involves the ordered occlusion of those
cues normally utilized by the performer.

(d) **Evaluation of Occlusion Procedures**

All these occlusion techniques proposed are limited by their
indirect approach to the assessment of cue usage and by the consequent
necessity for numerous separate experiments in order to isolate cue usage
to within a narrow range. Further, the probability that skilled performers utilize not one cue but a series of cues may well make interpretation of the results of the single temporal and spatial procedures difficulty and this, in turn, would compound the difficulty of selecting appropriate conditions for the 'spatial x temporal' procedure. In any case management of the occlusion paradigms requires the experimenter to have some preconceived ideas concerning what cues are important, and at what stage they are needed, and this may lead to the exclusion of some important cue sources from the outset. Additionally, trial-by-trial presentation of visual information for use with the occlusion procedures may reduce ecological validity due to the loss of sequential information (e.g. see Owens, 1979; Whiting, 1979) and raises the associated dilemma of whether or not to provide knowledge of results after each trial (Fleury, Bard & Carrière, 1982).

On the positive side the occlusion procedures do offer a relatively easily implemented procedure for determining cue usage which is not reliant on many of the assumptions and technical difficulties inherent with eye movement recording, the next approach to be considered.

3. The Eye Movement Recording Approach
(a) Applications

In sport science eye movement recording has, to date, been used mainly in conjunction with the subject's viewing of either static slides (e.g. Bard & Fleury, 1976a; Tyldesley, Bootsma & Bomhoff, 1982; Vickers, 1984) or dynamic film sequences (e.g. Bard et. al., 1980; Ritzdorf, 1983) depicting sport-specific stimuli. However, due to technological
advances in the eye movement recording technique, especially in terms of the availability of lighter, more mobile recording apparatus, eye movement recording in field settings is becoming more prevalent although field recording is still largely restricted to sports in which the subject is relatively stationary or the range of movement is quite restricted. This restriction on the subject's mobility explains the selection of field tasks which have been examined (i.e. the sport tasks of ice-hockey goal-keeping (Bard & Fleury, 1981), fencing (Bard, Guezennec & Papin, 1981), rifle shooting (Ripoll, 1983, 1984; Ripoll et. al., 1983, 1985), gymnastics evaluation (Neumaier, 1982) and contrived basketball shooting (Ripoll et. al., 1982)) and accounts for the dearth of literature examining visual search in fast ball sports in the natural setting.

(b) **Basis of the Eye Movement Recording Approach**

The basic function of all eye movements is to ensure that the most important visual information in the display can be sampled by the fovea which has the highest acuity of any portion of the retina. As foveal vision extends for only some 20° around the line of central fixation (Rayner, 1978) and as visual acuity falls off rapidly as the stimulus passes away from the fovea into the parafovea (the next 10° of visual angle), and then into the periphery, it is necessary for the performer to constantly adjust the position of the eye in order to maintain high visual clarity. The functional visual field is of elliptical shape, being of a greater range horizontally than vertically, and this consequently results in a larger number of eye movements being made in
the horizontal than in the vertical plane (Mackworth & Bruner, 1970; Stern & Bynum, 1970). It is the recording of these eye movements and the consequent determination of the performer's visual search (scan) pattern (i.e. the record of the sequential changes in ocular fixation brought about by the eye movements) which can then be used as a relatively direct indicant of perceptual strategy.

Search patterns inevitably consist of two different ocular states - the state where the eye is apparently stationary and information is extracted from the display (termed a fixation) and the state where the eye is moving, usually rapidly, from one fixation point to the next. Although a large number of different eye movements are possible (see Tursky, 1974 or Young & Sheena, 1975a) the most prevalent form of eye movement is the saccadic eye movement which carries the eye with a jerky action between fixations at velocities of up to 400-6000/sec (Young & Sheena, 1975a). Input of visual information is actively suppressed during saccades (Festinger, 1971; Volkmann, 1976) but the efficiency of the visual search process is apparently not greatly impaired because the saccades frequently coincide with discrete eye blinks (Stern & Bynum, 1970) and are so rapid as to usually only occupy some 10% of the total viewing time available (Noton & Stark, 1971). However, although the saccadic movement is itself of very short duration (30-120 msecs; Young and Sheena, 1975a) the preparation for such movement is relatively lengthy, with latencies in the order of 150-200 msec. being reported (Barber & Legge, 1976). These latencies clearly play an important role in the determination of the duration of the preceding fixation and
complicate the simple interpretation of cue importance from fixation duration.

Although there has been substantial interest in saccadic eye movements by motor behaviourists, principally as an avenue for testing notions of motor control (e.g. see Fuchs, 1976), it is the nature of the fixations evident in the search pattern, rather than the saccades, which provides the basis for determination of individual differences in cue usage and perceptual strategy. The frequently coined term of 'eye movement research' is therefore a little paradoxical when one considers the importance assigned to ocular fixations rather than movements (Cohen, 1978a) and indeed as Mackworth (1976, p. 174) notes the 'pause is mightier than the move'. The assumptions related to the use of data derived from these ocular 'pauses' in the determination of perceptual strategies in sport will be considered in the next section.

(c) Assumptions in Using Eye Movement Recording to Assess Cue Usage

The basic assumption underlying the assessment of cue usage from eye movement recording procedures is that the location, duration, and order of fixations evident in the scan pattern accurately reflect the underlying perceptual strategies used by the performers to extract information from the display. It is assumed consequently that the fixation characteristics provide a relatively direct indication of the

24. If corrections to saccade selection are required then refractory period effects are observed similar to those observed in manual tasks (Megaw, 1975).
manner in which the performer selectively attends to his/her display and the cues the performer utilizes in order to make task-relevant decisions. The evidence supporting the independent location, duration, and order assumptions will now be examined.

(i) **The Location Assumption**

It is assumed in the eye movement recording approach that the fixation locations correspond to the most relevant cue sources or to those sections of the display which are most likely to provide pertinent information and there are a number of lines of evidence from applied tasks which support these assumptions. Investigations of both skilled searching of radiographs (Kundel & LaFollette, 1972; Kundel & Wright, 1969) and normal picture viewing (Mackworth & Morandi, 1967), for example, have indicated that the initial fixations of the subject are largely based upon their expectations and *a priori* notions of where the critical display information is most likely to be located. For static display tasks such as these, the initial search appears to be guided by expectational information brought into the situation, while later search is determined by the flow of current information available from the display. Peripheral vision appears to be used to determine the most appropriate location point for subsequent fixations.

Evidence is also available to demonstrate a concurrence between the fixation characteristics of the scan pattern and known features of the performer's selective attention strategies. Large sections of task displays, for instance, are seldom searched by experienced performers with fixations being largely restricted to those sections of the display.
which have the highest probability of containing target information (Megaw & Richardson, 1979). In time-constrained tasks such as air-to-ground searching (Snyder, 1973) as many as 80-90% of the total fixations may be made within only 5% of the total available display. Although those areas of the display which attract fixations obviously vary from task to task, novel or ambiguous areas are frequently sampled on a wide variety of tasks (Gould, 1967; Lofthus & Mackworth, 1978; Mackworth & Morandi, 1967), particularly if such areas contain sharp visual contour (Kundel & Wright, 1969). Display areas which have been shown to be frequently ignored because of their low information content include the centre and extreme edges of radar screens (White & Ford, 1960), the edges rather than the inside boundaries of electrical chips (Schoonard, Gould & Miller, 1973) and the broad, uniformly-textured areas of pictures (Mackworth & Morandi, 1967), maps (Enoch, 1960) and radiographs (Lewellyn-Thomas & Lansdown, 1963; Kundel & La Follette, 1972).

The location of the performer's fixations also appear to be dependent upon what specific information has to be extracted from the display, with different scan patterns being evident when subjects are presented with a constant display but a variable instructional set (Yarbus, 1967). As a consequence sections of the display may vary dramatically as potential cue sources merely because of subtle alterations in the task requirements. The position of the kerb, for example, is only occasionally sampled during straight road driving but becomes one of the major fixation locations when the driver's task is changed to that of turning (Shinar, McDowell & Rockwell, 1977).
Similarly variations in the fixation locations of drivers occur dependent upon whether they are following another car or not (Cohen, 1978a) and variations in the ocular fixations of pilots searching their instrument panel display occur dependent on the stage of flight at which they are involved (Papin, Naureils & Santucci, 1980). Clearly contextual information exerts a quite powerful influence upon the determination of fixation location (see also Antes and Penland's, 1981 evidence from reading) suggesting that the recording of eye movement patterns does indeed provide information directly related to the perceptual strategies adopted by the performers of 'real world' skills.

The final evidence supporting the validity of the location assumption comes from the close correspondence which can be drawn between the fixation locations evident in the scan patterns and the subject's subjective estimates regarding the location of important information (Kundel, 1974; Mackworth & Morandi, 1967; Pollack & Spence, 1968; Schissler, 1969). Unfortunately the majority of evidence in this case has been drawn from tasks which are neither time-constrained nor utilize a dynamic display and obviously verification of this relationship is required for 'open' skills where dynamic events rather than stationary objects are the critical cues. As has been noted earlier with respect to verbalization techniques, the experienced performers may become unaware of their own cue usage and consequently discrepancies may arise between what they believe to be the most important display features and the cues they actually utilize. This possible discrepancy is, for example, one of the prime arguments advanced against universal acceptance of the concept of 'keeping the eye on the ball' as the key to success in fast ball
sports (Whiting, 1969).

(ii) The Duration Assumption

It is frequently assumed in visual search research that the fixation duration is in some way related to the importance of the item being fixated with long fixation durations being used to imply the fixation of a critical cue. Although fixation duration provides, at least for cognitive tasks with static displays, a fairly accurate estimate of the duration of the underlying cognitive processes (Gould, 1973), with fixation rates closely matching the rates of environmental change (Carpenter & Just, 1978a; Just & Carpenter, 1976), any assumption regarding the importance of the area being fixated must be questioned.

As early as the 19th Century Purkinje (1825), for example, had suggested that the relationship between fixation duration and information processing may not be a simple one but may rather be quite contingent upon the purpose for which any given fixation was made. When exploratory search was taking place, for example, it was expected that fixation durations would be shorter than in the case where normal viewing was taking place and, in turn, this situation was expected to produce shorter fixation durations than when the subject's fixations were non-functional and staring was occurring (Cohen, 1977). From this perspective it is then not surprising that in some cases a direct relationship between fixation duration and cue importance is observed (e.g. Papin, Naureils & Santucci, 1980 found more lengthy fixations by fighter pilots upon critical rather than non-critical features of their instrument panel)
whereas in other cases (e.g. Vaughan, 1978) fixation duration is implied to be independent of the visual information being extracted.

Furthermore it needs to be recognized that the time spent at any given fixation location is unlikely to be devoted totally to active information extraction and this works against a simple fixation duration-cue criticality relationship. Fixation duration, it has been previously noted, consists of not only the cognitive processing time, in which information is extracted from the particular fixation locus, but also the time necessary to determine the next fixation location and initiate the subsequent saccade (the oculomotor period) (Salthouse, Ellis, Diener & Somberg, 1981; Vaughan, 1982). Clearly, a long fixation duration could be observed either when the information at the current location is for some reason difficult to extract (a cognitive delay problem) or when the next location is difficult to determine or to reach (an oculo-motor delay problem). In both cases the extension of the fixation duration would be unrelated to the importance of the area currently fixated and the duration assumption would be violated.

Fixation duration, then, should be regarded as a very useful parameter for describing visual search, but it should not, by itself, be used as a single criterion for assessing cue usage and importance (Cohen, 1977; Just & Carpenter, 1976). Although fixation duration, as an indicant of search rate, may be the most stable search characteristic over time (Buchsbaum, Pfefferbaum & Stillman, 1972), there is an ever present possibility that some trade-offs may exist between duration and the other fixation parameters of location and sequence. For this reason
continuous assessment of all three of these parameters is necessary in order to construct a comprehensive picture of the performer's cue dependence and perceptual strategy (Johnston & Pirozzolo, 1981).

(iii) The Order Assumption

Another commonly held assumption in much of the visual search literature is with the existence of a direct correspondence between the order in which the features of the display are fixated and the priority the subject gives to these features as sources of task-relevant information. Although such a correspondence is frequently observed for cognitive tasks with static displays (Just & Carpenter, 1976) this order assumption is clearly not appropriate for the dynamic displays found in fast ball sports. For these tasks, which are characterized by a changing display, the fixation order will be determined rather by the time at which certain informational events become available within the display sequence. Procedures for identifying search order and sequential characteristics have been established for some ergonomic tasks, viz. industrial inspection (Megaw & Richardson, 1979) and aircraft control (Carbonnell, Ward & Senders, 1968), but with the exception of recent French works (Bard et al., 1981; Ripoll et al., 1983, 1985; Ripoll, 1984) visual search order characteristics have not been examined in great detail within sport task settings.

(d) Limitations in the Eye Movement Recording Approach

Despite the high hopes held for eye movement recording as an avenue for advancing sports science knowledge (e.g. see Rothstein, 1977a;
Terauds, 1976) and its increasingly persistent use as a tool for sports science research, a number of important limitations exist in the approach, which are infrequently acknowledged. In applying eye movement recording methods to 'real world' skills the technical and methodological limitations in the eye movement recording approach take on particular significance (Lévy-Schoen, 1983). Most notably there are problems related to discrepancies between attentional allocation and eye movements, problems related to the extent of search specificity and intra-subject variability, problems related to measurement error and problems related to the selection and implementation of analysis procedures which need to be considered.

It has been recognized for some time that it is possible to shift attention around the visual field without any eye movements, or change in fixation, being elicited. Helmholtz (1909), for example, reported this phenomenon, by stating that

'... it is a curious fact that the observer may be gazing steadily at the fixation mark, and yet at the same time he can concentrate his attention upon any part of the field he likes'.

More recently this shifting of attention across the visual field has been shown to occur without the loss of input information usually associated with saccadic eye movements (Gippenreiter & Romanov, 1974; Kaufman & Richards, 1969; Posner, 1980; Remington, 1980; Shulman, Remington & McLean, 1979; Sperling & Reeves, 1980; Wolff, 1984) and these shifts can be matched directly to imposed performer strategies (Klein, 1979). The performer's capacity for making internal attentional shifts
facilitates the acquisition of information from the visual periphery and
indeed 'a fixation may be merely a reference point for organisation of
peripherally acquired information' (Rockwell, 1972, p. 154). The
probability that considerable relevant information for fast ball sport
performance is acquired through the periphery highlights a substantial
limitation in the eye movement recording procedure, which can only provide
assessment of foveated stimuli (Cohen, 1978a).

A second limitation arising out of the existence of internal
attentional shifts is with the distinction which needs to be drawn
between the phenomena of 'looking', which implies a physical orientation
towards a stimulus in the form of a fixation, and 'seeing', which implies
actual perception or information extraction (Adams, 1966; Mackworth,
Kaplan & Metlay, 1964). This distinction is supported by the frequent
occurrence of target objects being fixated in applied visual search
tasks, without the performer actually detecting the target's presence.
For example, Snyder (1973) and Stager and Angus (1978) in investigations
of air-to-ground searching have both reported instances where the target
object (a crash site) has been fixated but not reported and Thomas (1968)
reports data from car drivers which indicates the frequent presence of
fixations upon red traffic lights without any concomitant driving
adjustment.

A further problem which arises in interpreting the results of eye
movement recording procedures is with the absence of comprehensive trial-
to-trial replicability in the scan patterns for even static displays
(Noton & Stark, 1971). When dynamic display skills are examined and
events rather than objects become the critical features of the scan path the extent of this between-trial variability may increase and compound the interpretation difficulties even further.

Variations in search parameters both between- and within-subjects are a dominant feature of visual search activity (Bouma, 1978) and massive individual differences in search strategy are apparent even when seemingly homogeneous groups are examined (e.g. Megaw & Richardson, 1979; Ripoll, 1984; Ripoll et. al., 1985). Scan patterns also tend to be highly task specific (Peterson, 1969) and this may result in scan pattern changes resulting merely from the transition of the subject from the performance setting to the experimental setting (Cohen, 1978a) or, from a situation where the search patterns are not being recorded, to a situation where recording is taking place.

Assessment of cue usage from eye movement recording is also impeded by substantial technical limitations inherent in the eye movement recording approach. Selection of an appropriate recording technique involves consideration of a multitude of factors including measurement range and accuracy (including the concern of whether or not microsaccades need to be examined, Ohtani, 1971), calibration and set-up time, degree of subject discomfort, degree of interference with normal vision and normal mobility, the accessibility of the output format, data handling time, and of course, operational cost (Megaw & Richardson, 1979; Young & Sheena, 1975a) with the principal trade-off being that between accuracy and expenditure (Cohen, 1978a).
The most appropriate technique for research of 'open' motor skills appears to be to use a head-mounted corneal reflex camera, or eye mark recorder (Simmons, 1979; Terauds, 1976) similar to that originally developed by Mackworth and Mackworth (1958). With this method a parallel beam of light is directed at the cornea and the reflected light spot collected and combined with the input from a head-mounted scene camera to provide an output which consists of a view of the scene the subject is observing with a fixation spot superimposed upon that section of the display which is being fixated. Although the output is in a format which can be easily recorded and interpreted, the use of this technique does present some problems in terms of possible subject discomfort due to the weight of the head-mounted camera and the necessity, in many cases, for subjects to wear a bite bar to maintain alignment of the recording device upon the head. Some of these difficulties have been alleviated in the more recent commercial models (such as the NAC EMR-IV and EMR-V) in order to facilitate field recording although some modifications in the recording device are still frequently needed in order to record search patterns in situations where the subject needs to be totally mobile (e.g. see Muffang et al., 1983).

Corneal reflection procedures are reportedly accurate to some 2° within a 20° measurement range (Young & Sheena, 1975a) although in many instances in reality this level of accuracy may not be achieved. Consequently the use of this, and other, eye movement recording methods to assess cue usage and perceptual strategies necessitates a compromise in terms of the size of the film image being viewed. The image needs to
be sufficiently far from the observer to remain within the acceptable angular range but still needs to be large enough to allow the fixation mark to be clearly related to one section of the display only. More detailed descriptions of the available eye movement recording techniques and discussions of their respective advantages and limitations may be found in Tursky (1974), Young and Sheena (1975a, 1975b), Monty and Senders (1976) or Stern, Ray and Davis (1980).

Irrespective of the recording procedure, fundamental difficulties are also encountered in the selection of appropriate parameters to describe visual search performance. As no single parameter appears to be capable of succinctly describing all features of the performer's visual search strategy (Cohen, 1977) it is necessary to record not only fixation duration but also fixation order, location, and frequency and, where appropriate, decision time. Therefore, although the problem of describing the observed search patterns is not an insurmountable one, it does necessitate the collection and analysis of substantial amounts of data even for very short time periods, and this has, in turn, lead to incorporation of on-line computer analysis procedures (e.g. Anliker, 1976; Fisher & Rothkopf, 1982; Kliegl, 1981).

(e) Evaluation of Eye Movement Recording Procedures

Clearly, the eye movement recording approach incorporates a number of assumptions and limitations which need to be carefully considered before any assessment of perceptual strategies in fast ball sports is made. Despite these limitations the value of eye movement recording in providing a direct means of assessing cue usage needs to be recognized
and with careful experimental design some of the perceived problems with eye movement recording may be alleviated. For example, as Cohen (1978a) has suggested, design of studies to incorporate a high foveal load and high time constraints may partially alleviate the potential problems related to the inability of eye movement recording methods to assess peripheral visual usage and to identify the use of fixations which serve no particular task-related function. The problem of accounting for attentional shifts unrelated to fixation changes may, however, require the use of some concomitant direct measure of task performance to ensure information extraction is actually related to the search activity (or inactivity) observed. All things considered therefore, eye movement recording does appear to provide a unique means of deriving meaningful information regarding the cues used by individual subjects and provides an objective basis for comparing individual differences in perceptual strategy. The limitations and assumptions associated with the use of this method clearly need to be fully understood however.

IV: PARADIGM ASSESSMENT AND SELECTION

In order for a paradigm to provide a meaningful contribution to perceptual and cognitive research in sport it appears necessary that the paradigm should fulfil criteria related to (i) the presence of a sport-specific focus, (ii) the maintenance of ecological validity, (iii) the incorporation of multiple levels of analysis and (iv) the examination of individual differences (Salmela, Partington & Orlick, 1982, p. 20). Having already decided that a laboratory approach rather than a field
method appears appropriate at this stage the process of selecting a paradigm for studying perceptual strategies in sport then simply becomes that of selecting the laboratory paradigm which best fulfils these four criteria. Unfortunately however, all the existing laboratory (film-based) paradigms have assumptions and limitations which make their use a little tenuous and they have, to date, been utilized with little regard for their respective reliabilities and validities etc.

**Multi-Procedural Approaches**

In view of the quite substantial limitations evident in each of the approaches examined it would appear that the best approach to assessing cue usage currently available may be achieved by combining a number of the procedures already discussed. In particular, there would appear to be considerable merit in combining the film occlusion procedures (both temporal and event) with simultaneous eye movement recording as this could provide three essentially independent assessments of cue usage. The advantage of this particular multi-procedural approach is that it provides not only a reduced probability of incorrect assessment, but also, in part, allows the limitations in each individual procedure to be counteracted by the other. For example, the difficulty in eye movement recording of determining whether a subject is actively perceiving or merely passively looking can be at least partially overcome by examining the simultaneous accuracies from the occlusion procedures. Conversely the effect that selective occlusion of cue sources (event occlusion) has on the subject's perceptual strategies, can also be confirmed through examination of any concurrent alterations in the scan pattern data.
This multi-procedural approach easily meets three of the four criteria for perceptual research in sport proposed by Salmela, Partington and Orlick in that it can use sport-specific stimuli (through the use of these stimuli in the film occlusion tasks), it is based upon the use of multiple levels of analysis (including measurement methods drawn from both the behavioural and psycho-psychological streams of motor behaviour; Kleinman, 1983, pp. 12-29) and it is directed at the determination of individual differences in perceptual strategy. However, because of the reliance on film simulation of the display for the presentation of the occlusion tasks, ecological validity (the final criterion of Salmela, Partington and Orlick) in this paradigm may be somewhat less than that of the 'real world' setting. Nevertheless some steps can be taken to assess the relative ecological validity of different aspects of the film task by direct comparison of task features such as attention demand between this laboratory setting and the natural setting.25

Film Task Construction and Design

The construction of a film task, as part of this multi-procedural approach to assessing perceptual strategies, must necessarily be based on an attempt to compromise the need for preserving ecological validity with the need to retain experimental control within the occlusion paradigm. The film task developed for use in all eight experiments in this thesis focusses on the sport of badminton and attempts to retain ecological

25 In experiments described in Chapter 6 the ecological validity of this paradigm is assessed in part by comparison of the attention demands of responding to the film task with the demands in the sport-specific setting (Experiment 3).
Figure 19: Camera positioning for the badminton film task.
validity by accurately simulating the viewing perspective and task demands of a badminton player placed in a variety of game-like situations. The sport of badminton was chosen as representative of fast ball sports because of its playing speed, the prevalence and importance of deceptive skills to the game outcome, the relatively narrow perceptual field presented (thereby limiting uncontrollable peripheral processing demands) and the dearth of scientifically based research available on this sport.

(a) **Film Task Construction**

One provincial-level male badminton player was filmed executing a series of fundamental badminton strokes in response to shuttles fed to him by a confederate player located out of camera view. Filming, using a 16mm colour camera operating at 24 frames/second, was done from a mid back-court position (see Figure 19), typical of a player's receiving position in badminton, and the camera height was adjusted so as to film a display comparable to that seen by an opponent during an actual game. No attempt was made by the filmed player to disguise his stroke execution beyond normal levels and the origins and actual landing positions of all strokes filmed were recorded.

From the 180 strokes originally filmed 32 individual strokes were selected for use in the film construction proper with these selected strokes consisting of four partial replications of each of eight different stroke types. These eight stroke types consisted of all possible combinations of forehand and backhand strokes, smash and drop-
Condition t1
Occlusion 4 frames (167 msec) prior to contact point.

Condition t2
Occlusion 2 frames (83 msec) prior to contact point.

Condition t3
Occlusion at contact point.

Condition t4
Occlusion 2 frames (83 msec) after contact point.

Condition t5
No Occlusion.
Full display information available.

Figure 20: Examples of the final frame of information presented under each of the five temporal occlusion conditions.
shots, and cross-court and down-the-line strokes, with the partial replications consisting of similar but not identical strokes within each of the stroke type categories. Multiple copies of each of these selected strokes were then made and edited together in such a fashion as to create a final film task in which there were 320 trials in all consisting of 10 replications of each particular stroke. The order in which the various strokes and replications occurred was randomized across the film.

(b) **Film Task Design**

Each of the 10 occurrences of each of the 32 strokes which went to make up the film task was under a different condition of either temporal or event (spatial) occlusion. There were five temporal occlusion conditions in all which varied in the amount of temporal information that was available to the viewer prior to the display occlusion. These temporal occlusion conditions were:

- **t1**: Occlusion occurred 4 frames (~167 msec) prior to racquet-shuttle contact
- **t2**: Occlusion occurred 2 frames (~83 msec) prior to racquet-shuttle contact
- **t3**: Occlusion occurred at the point of racquet-shuttle contact
- **t4**: Occlusion occurred 2 frames (~83 msec) subsequent to racquet-shuttle contact
- **t5**: No occlusion occurred.

The control condition (t5), in which the full time course of display information was provided to the subjects, provided more shuttle flight information than t4 although the extent of additional flight information
Condition e1
Occlusion of playing side arm and racquet.

Condition e2
Occlusion of racquet only.

Condition e3
Occlusion of player's hand and face.

Condition e4
Occlusion of player's lower body.

Condition e5
Occlusion of irrelevant background features.

Figure 21: Examples of the final frame of information presented under each of the five event occlusion conditions.
varied according to the stroke type. More frames of shuttle outflight, for example, were visible for drop shots than for smash shots. Figure 20 provides an example of each of these respective temporal occlusion conditions for one particular stroke—a forehand smash cross-court.

The remaining five occlusion trials per stroke were presented under conditions of spatial or event occlusion. Using a constant time course of display information equivalent to the temporal occlusion condition t3 (i.e., an occlusion of all information subsequent to racquet-shuttle contact) different cue sources available in the display were selectively occluded through the placement of black letraset mats upon the positive film surface. The five event occlusion conditions were then:

- **e1** - the player's racquet and the arm holding the racquet were occluded
- **e2** - the player's racquet (but not the arm holding it) were occluded
- **e3** - the player's face and head were occluded
- **e4** - the player's lower body (from the waist downwards) was occluded
- **e5** - an irrelevant background feature was occluded.

In the final event occlusion condition (e5) different sections of the background unrelated to the player's stroke execution were randomly occluded to provide a control condition which could account for possible decrements in task performance due to distraction by the occluding mats rather than due to a loss of a relevant cue source. The extent of the distraction caused by the event occlusion process was determinable through comparison of subject performance on the occlusion conditions t3
and e5. Examples of each of the event occlusion conditions are given in Figure 21.

In summary then, the design used in the construction of this film task consisted of:

- 320 individual trials
- made up of: 32 individual strokes x 10 replications
- composed of: (8 stroke types x 4 replications) x 10 occlusion conditions
- and consisting of:
  - 2 forehand - backhands x
  - 2 smash - drop shots x
  - 2 cross court - down line x
  - 4 partial replications x
  - 10 occlusion conditions

The order and description of all 320 trials, along with data on the actual origin and landing position of each trial, are available in Appendix B-2.

All presentations of the same stroke or stroke type, regardless of occlusion condition, had an essentially constant duration of preliminary player activity leading up to racquet-shuttle contact, with the film sequences generally commencing with the player in a balanced, waiting position around mid-court. All trials were followed by a 5 second inter-trial interval, controlled through the use of dark leader tape, allowing relatively strict temporal constraints upon the performers to be
maintained and negating possible individual differences in the time taken to process, rather than extract, visual information from the display. (More details of the specific judgmental tasks used with this film display are given in the method section of each of the experiments described in the forthcoming chapters).

(c) Film Presentation

In the constructed film all temporal occlusion trials occurred before the event occlusion trials, with each set of 160 experimental trials being preceded by a short set of practice trials. Six practice trials were provided to familiarize subjects with the temporal occlusion trials and four further practice trials were provided prior to the commencement of the event occlusion condition. The film also included, following the event occlusion condition, the presentation of a set of six random alphanumeric displays (presented in a 4 x 4 matrix). These displays were presented for only brief viewing times (approximately 300 msec.) in order to examine individual differences in the capability of subjects to extract non-specific visual information presented rapidly on a film display. In all the total film task duration was in the order of 40 minutes.

Application of this film task, in conjunction with concurrent eye movement recording, is made in the next chapter to consider proficiency-related differences in the perceptual strategies of elite and novice badminton players.

IV : SUMMARY
In previous chapters it has been noted that the uncertainty associated with the perceptual display in fast ball sports makes it necessary for the skilled performer to select and utilize only a limited number of highly pertinent display features as cues. In view of limited current knowledge regarding (a) the task-specific location of pertinent cue sources and (b) proficiency-related differences in cue usage, a number of potential procedures for isolating perceptual strategies in sport have been examined in this chapter. It has been suggested that although field procedures are undoubtably advantageous for the maintenance of ecological validity, laboratory procedures based around film simulation of the performer’s display are necessary at this stage of technical development in order to obtain acceptable levels of experimental control and replicability. Applications, assumptions, and limitations of three film-based procedures were considered in this chapter and a paradigm for investigating perceptual strategy differences in sport was ultimately selected which involved the combination of eye movement recording with the occlusion of time sequences and specific events in the film display. The specific film task designed to determine the time and spatial location of critical cues in badminton was consequently outlined in detail, and it is this film task which forms the basis for the experimental investigations of proficiency-related differences in perceptual strategies which fill the remainder of this thesis.
CHAPTER 5

PROFICIENCY-RELATED DIFFERENCES IN PERCEPTUAL STRATEGIES
IN A RACQUET SPORT

Information processing notions of selective attention, and available sport-specific evidence (Chapter 3), lead to a number of expectations regarding skill-related differences in perceptual strategies in sport. Specifically theories of selective attention predict differences between expert and novice fast ball sport performers in terms of the specific cues they utilize, the search strategies or order of information extraction they adopt and in the rates at which they are forced to search the display in order to extract task-relevant information. In this chapter these predicted differences in perceptual strategy are examined using the multi-procedural paradigm proposed in the previous chapter.

Specifically, the following hypotheses regarding proficiency-related differences in perceptual strategy will be tested through the combined use of the film occlusion and eye movement recording paradigms.

Hypothesis 1: Experts are more aware of the redundancies existing in the perceptual display than are novices and can therefore extract more information from earlier, advance cues than can novices.

Supporting evidence for this hypothesis can be derived from the temporal occlusion conditions of the film task described in the previous chapter and would include either

(a) superior performance by the expert performers on the
more difficult temporal occlusion conditions (viz t1 and t2)
or (b) earlier and greater gains in performance by the expert performers between successive occlusion conditions (e.g. t1 - t2 and t2 - t3) (See Figure 17 for examples of these differences).

Hypothesis 2: Experts attend to more relevant sources of information (and hence give less attention to irrelevant sources) than do novices resulting in experts using different cues to those used by novices.

This hypothesis would be supported by either

(a) proficiency-related differences in response error on the event occlusion conditions of the film task (see Figure 18)
or (b) different fixation location distributions for experts and novices from the visual search analysis.

Hypothesis 3: Experts need to process less environmental information than do novices; therefore experts will search the display at a slower rate, making more efficient use of peripheral vision and the relative viewing time allocation to fixations and saccades.

This third hypothesis would be supported, in the scan pattern analysis, by a greater mean fixation duration (and hence slower search rate) for experts than novices.

In the two experiments described in this chapter these hypothesized
differences in perceptual strategy are examined in the fast ball sport of badminton, using the film task described in Chapter 4 and a sample of experts and novices of sufficient size to alleviate many of the sampling and statistical limitations evident in earlier sport-specific tests of selective attention. In Experiment 1 only film-occlusion task data is considered whereas in Experiment 2 the concomitant eye movement recording data is also examined.

I: EXPERIMENT 1

Method

Subjects A total of 55 subjects participated in this experiment – 20 of these subjects were classified as expert badminton players and the remaining 35 were classified as novices. All expert players were participants in the 1982 Commonwealth Games badminton competition in Brisbane, Australia and were therefore all National representatives. Eight of the expert players were Australian team members, six were New Zealand team members, four were Canadian team members and two of the participants were from the English team. This expert group ranged in age from 18 to 32 years and consisted of both male and female players (13 of the expert group were males and 12 were female).26

26. As both males and females frequently compete against each other at International Level in mixed doubles competition gender was not expected to be an important variable in perceptual performance. However, the presence of any gender effect upon task performance was, still monitored throughout the course of the experiment. The inclusion of both male and female subjects in the samples allowed larger, more acceptable sample sizes to be achieved.
The novice group, consisting of 22 males and 13 females ranging in age from 18 to 29 years, was drawn from a population of students from the Faculty of Physical Education, University of Otago, New Zealand. Subjects in this group were not, and had not been, regular participants in badminton at either a competitive or social level. All subjects had, however, seen badminton played and were given an orientation to the dimensions of a badminton court prior to the commencement of the experiment.

Testing of the subjects took place at three separate venues. Expert subjects, who were members of the New Zealand national team, were tested during the period of their National Championships from August 31st to September 4th, 1982 at a venue in the Hamilton Teacher's College. The remainder of the expert group were tested in the week prior to the XII Commonwealth Games (September 21-28th, 1982) at the Games Village, Griffith University, Brisbane while all novice subjects were subsequently tested in the months of March and April, 1983 at the University of Otago.

**Apparatus** A 16mm Lafayette Model 224-A-MK VII Data Analyzer projector operating at normal projection speed of 24 frames per second was used to present the film occlusion tasks. The projector was set at a distance of 5 metres from a white projection screen enabling a 1.00 x 0.75 metre image size to be presented. The subject was seated some 4 metres from the viewing screen with the screen positioned so that the lower edge of the screen was approximately at the eye level of the subject in his/her seated position. Throughout the course of the experiments the subjects sat behind a standard table, upon which the response sheets for the task were placed. (Figure 75 for a more detailed
Figure 22: Response sheet used for the landing position predictions required in Experiment 1. The actual response sheet used was scaled to 152 x 167 mm size and two such response sheets were provided side-by-side on each foolscap sized page to aid data collection and storage.
view of the experimental set-up).

Procedures. Subjects were presented with the film task described in Chapter 4 and were instructed to consider the display presented to them as being comparable to that which they would receive if they were in an actual game situation. Subjects were informed of the camera position (a mid-back-court position) and were therefore requested to consider the display available to them as being that which would arise from that viewing position in an actual game setting. The subject's task, on each film trial, was to determine from the film display presented to them, the probable landing position of the opponent's stroke and to then, during the 5 second inter-trial interval, mark this predicted landing position down on the response sheet provided. The response sheet was a scaled representation of the receiver's half of a badminton court (see Figure 22) and a different response sheet was used for each trial. The subjects were required to manually change the response sheets between trials and were instructed therefore, because of the short inter-trial interval, to make their response selection decision immediately after the film information was extinguished. Even in cases of total uncertainty as to the landing position subjects were still requested to make a prediction response.

All subjects performed the film occlusion test conditions in the order specified in the film construction (i.e. temporal occlusion trials followed by event occlusion trials followed finally by the unstructured letter matrices test) with the actual film test taking, on average, approximately 40 - 45 minutes. Subjects were advised that they could
Figure 23: Derivation of the prediction error measures for Experiment 1. Depth, lateral and angular error terms were derived as signed (i.e., either positive or negative) values but were also expressed for analysis purposes in absolute terms.
request a rest at any time during the film test but were encouraged to use only those rest periods provided after each block of 80 trials. At the completion of the film task all subjects were interviewed regarding their perceptions of task difficulty and of the reality of the test situation and a subjective assessment by the subjects of their normal patterns of cue usage in play situations was sought. All subjects were informed of their right to withdraw from the experiment at any stage.

**Analysis of Data**  
X - y co-ordinates of the subject's perceived landing position responses were derived from the response sheets using a SAC (Science Accessories Corporation) Sonic Digitizer (Grafbar Model GP-7) and were scaled to real court dimensions using a scale factor of 1 inch : 1.044 metres. For each trial the discrepancy between the subject's prediction of the landing position of the shuttle and it's actual landing position was calculated using the fortran computer program tennis·for, (see Appendix B-3) and the following dependent error measures were derived for each trial:

(a) **lateral error**, which was the signed horizontal directional error in judgment - a positive lateral error was indicative of the predicted landing position being placed to the left of actual, a negative lateral error was indicative of the predicted landing position being to the right of actual.

(b) **depth error**, which was the signed error in landing position distance judgment - a positive depth error
# TABLE 5

Independent and Dependent Variables in Experiment 1

### A. INDEPENDENT VARIABLES

**Between Group Factors**
- Proficiency (2 levels)
- Gender (2 levels)

**Within Group Factors**
- (i) Occlusion Conditions
  - Temporal Occlusion Conditions (5 levels)
  - Event Occlusion Conditions (5 levels)
- (ii) Stroke Types
  - Forehand-Backhand Strokes (2 levels)
  - Cross-court – Down-line Strokes (2 levels)
  - Smash shots – Drop shots (2 levels)
- (iii) Replications
  - Stroke Type Replications (4 levels)

### B. DEPENDENT VARIABLES

- (i) Discrepancy between predicted and actual landing position
  - Lateral error (signed or unsigned)
  - Depth error (signed or unsigned)
  - Radial error
  - Angular error (signed or unsigned)
- (ii) Deviation of predicted landing position from court centre
  - Lateral deviation (signed or unsigned)
  - Depth deviation (signed or unsigned)
  - Radial deviation

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a - In signed error terms the direction of error is considered as with traditional constant error measures. In unsigned error terms the direction of the error is disregarded and only the absolute error is considered.
indicated the subjects predicted the landing position to be longer (i.e. closer to the baseline) than it actually was, a negative depth error indicated that the subjects had under-estimated the distance the shuttle would travel.

(c) **radial error**, which was the unsigned composite of both lateral and depth error derived through the theorem of Pythagoras.

and (d) **angular error**, which was the signed angular error in directional judgment with positive and negative values carrying the same meaning as for the lateral error term.

Examples of the derivation of each of these error scores is given in Figure 23.

In addition, on each trial, the deviation of the response given from the centre of the receiver's court was also calculated and expressed in lateral, depth and radial terms. For any trial in which subjects had not made a response, each of the error terms were estimated by taking the mean value of the responses made to the three other partial replications of the same stroke type and occlusion type which were built into the experimental design.

Differences between levels of selected independent variables used in this study (see Table 5) on each of these error measures were then assessed by first selecting out the required factors and dependent
Figure 24: Radial error in the prediction of shuttle landing position as a function of the degree of temporal occlusion for the expert and novice groups in Experiment 1.

Significant differences exist between the groups on all conditions except t1. For the expert group significant reductions in radial error occur from t1-t2, t2-t3 and t3-t4 whereas for the novice group significant reductions only take place between t2 and t3 and t3 and t4.
measures (using the fortran program tanova.for, see Appendix B-5) and by then subjecting the data to a factorial analysis of variance (using the unix system program anova27). The sources of any significant main or interactive effects were sought through the use of the Newman-Keuls post-hoc procedure, with an alpha level of 0.05 being pre-selected for all statistical comparisons. All computations were performed on a DEC (Digital Equipment Company) PDP 11/34 minicomputer.

**Results and Discussion**

**(a) Analysis of Proficiency Level Effects**

**Temporal Occlusion Analyses**

**(i) Radial Error** Figure 24 presents the mean radial error in landing position for the expert and novice badminton groups over each of the five temporal occlusion conditions. A significant interaction exists between playing proficiency and the temporal occlusion conditions \((F(4,212)=8.134, p<.05)\)28 and this is attributable to the superior performance of the expert badminton players on all conditions of occlusion with the exception of t1. Consequently when display information is occluded at any time after a point some 170 msec prior to racquet-shuttle contact experts show a superior capability to use the available display information to arrive at a prediction regarding the opponent's forthcoming stroke.

When the skill groups are compared in terms of their ability to improve their prediction accuracy across successive temporal occlusion

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27. Written by G. Perlman - See Perlman (1980).

28. The source tables for all analyses of variance performed in Experiment 1 are provided in Appendix G.
conditions some crucial information processing differences appear to emerge. Whereas the expert players display an ability to reduce their prediction error with each successive gain of 84 msec viewing time from \( t_1 \) right through to \( t_4 \) (indicating that each gain in display information from 168 msec prior to contact \( (t_1) \) to 84 msec after contact \( (t_4) \) aids in resolving situational uncertainty) the novice players only appear to be able to extract pertinent information for prediction in the period from 84 msec before racquet-shuttle contact \( (t_2) \) to 84 msec after contact \( (t_4) \). Most notably experts show an ability to extract information in the period from \( t_1 \) to \( t_2 \) which can aid significantly in the prediction of the forthcoming stroke whereas novices in this same period appear unable to extract any information which can be used to resolve uncertainty about the developing stroke. The evidence available here therefore points strongly in favour of a greater capability of expert performers to recognize early redundancy in the display of their opponent and implicates this extraction of usable information in the period between 168 \( (t_1) \) and 84 \( (t_2) \) msec prior to the point of contact as the probable origin of the prediction differences which are evident across all the remaining occlusion conditions.

For both skill groups, prediction performance asymptotes between occlusion conditions \( t_4 \) and \( t_5 \) indicating the redundant nature of the information provided by later stages of shuttle outflight. Apparently brief, early viewing of shuttle flight (i.e. in the period \( t_3 - t_4 \)) is sufficient to extract all the potential information carried by shuttle flight which is of use in the prediction of the final landing position.
Figure 25: Absolute lateral error in the prediction of the shuttle landing position as a function of the degree of temporal occlusion for the expert and novice groups in Experiment 1. Significant differences exist between the groups on all conditions with, for both groups, significant reductions in error occurring from t1-t2, t2-t3 and from t3-t4.
As the radial error measure is actually a composite term related to errors in both the judgment of object direction and object speed it is desirable to consider these components separately. Independent consideration of the effect of different levels of temporal occlusion upon these components of prediction performance can be made by examination of the lateral and depth error measures.

(ii) **Lateral Error** The absolute lateral errors in judgment made by experts and novices at each of the five temporal occlusion conditions is shown in Figure 25. Significant main effects for proficiency \((F(1,53)=6.105, p<0.05)\) and for temporal occlusion \((F(4,212)=555.087, p<0.05)\) are evident in this case, but there is no interaction between these two factors as there was for the radial error measure \((F(4,212)=1.710, p>0.05)\). At all five conditions of temporal occlusion the absolute lateral error in the novice's prediction is greater than that for the experts, indicating a persistent superiority for the expert players in terms of their capability to extract information for the formulation of directional judgments.

For both groups significant gains in lateral prediction accuracy are made across all temporal increments from \(t_1\) through to \(t_4\), although clearly the greatest resolution of uncertainty regarding stroke direction is made in the 80 msec periods just preceding and just after the point of racquet-shuttle contact. These periods are therefore implicated as the critical time periods for information extraction regarding object directionality. Again, as no changes in prediction performance are apparent between \(t_4\) and \(t_5\), the visibility of only small portions of
Figure 26: Signed lateral error in the prediction of the shuttle landing position as a function of the degree of temporal occlusion for the expert and novice groups in Experiment 1.

The positive lateral error for the expert group at t2 differs significantly from all other data points.
shuttle flight appears to be sufficient for both groups to resolve all stroke direction uncertainty.

When directional bias in lateral error is considered (see Figure 26) it becomes apparent that the lateral errors in judgment made are primarily negative i.e. errors in which the perceived landing position of the shuttle is placed to the right of the actual landing position. Significant differences between the two skill groups are evident on only one of the temporal occlusion conditions (F(4,212)=4.774, p<.05), that being the condition t2. The lateral error for experts on this particular occlusion condition is the only instance of positive error observed, and this data point differs from all other constant lateral error scores obtained. As one would expect the directional bias evident in lateral error is generally non-systematic across the occlusion conditions therefore indicating that only the magnitude and not the direction of the lateral errors (as shown in the previous absolute lateral error analysis) varies systematically as a function of the subject's expertise and the temporal difficulty of the task.

(iii) Depth Error When errors in depth prediction are considered (Figure 27) it is apparent that although an overall superiority in depth judgment occurs for expert performers (F(1,53)=35.687, p<.05) the extent of this superiority is dependent upon the severity of the temporal occlusion presented F(4,212)=15.094, p<.05). Experts predict the landing depth, and hence the 'force' of the stroke, with greater accuracy than do novices in all but the earliest condition of temporal occlusion (i.e. t1). As was the case with the radial error measure experts, but not
Figure 27: Absolute depth error in the prediction of the shuttle landing position as a function of the degree of temporal occlusion for the expert and novice groups in Experiment 1.

Significant differences exist between the groups on all conditions except t1. For the expert group significant changes in depth error occur from t1-t2 and from t2-t3 whereas for the novice group significant differences exist between t2 and t3 and t3 and t4.
novices, show an ability to significantly reduce their depth prediction error from $t_1$ to $t_2$ indicating that the extraction of early information available between 168 and 84 msec prior to contact is dependent upon the subjects task-specific proficiency. Early cues are therefore available to facilitate the prediction of stroke depth by expert subjects but not by novices and this earlier resolution of depth uncertainty by experts may account for the earlier initiation of forward-backward movements which are frequently reported for expert performers in other fast ball sports (e.g. see the earlier foot movements for elite cricket batsmen reported in Figure 4).

For both skill groups information available in the period from 84 msec before contact ($t_2$) up to the point of racquet-shuttle contact ($t_3$) appears most critical for the normal perception of stroke depth and for both groups the major increments in depth prediction accuracy are obtained in this period. Surprisingly, information available after contact (i.e. shuttle flight information) does not appear to provide any additional information regarding landing depth beyond that already available from advance sources and indeed for the novice group vision of shuttle outflight actually detracts significantly from the prediction of landing depth. The novice group's non-familiarity with the flight idiosyncracies of a shuttlecock may account for this apparent confusion in the prediction of landing depth brought about by viewing the early stages of outflight. The extent to which the degradation of stereoptic cues due to the use of a two-dimensional film display contributes to this pattern of post-contact depth error is, however, difficult to determine.
Figure 28: Signed depth error in the prediction of the shuttle landing position as a function of the degree of temporal occlusion for the expert and novice groups in Experiment 1.

Significant differences exist between the groups on all conditions. For the expert group significant differences exist from t3-t4 and from t4-t5 whereas for the novice group significant differences exist from t1-t2, t2-t3 and t4-t5.
Systematic differences in the direction of the errors in depth judgment made by expert and novice performers are evident when the measure of constant depth error is considered (see Figure 28). Significant overall differences in constant depth error exist between the two skill groups ($F(1,53)=13.267,p<.05$) and this is apparently due to the consistent over-estimation of stroke depth by novices and the consistent under-estimation of stroke depth by experts, especially under the earlier occlusion conditions. The robust nature of these directional effects, which bring about significant differences between the skill groups on all five occlusion conditions, suggests that the observed depth errors are not merely an artifact of the use of a two-dimensional display presentation but are also a consequence of the performer's experience with the specific flight characteristics of a struck shuttlecock. A feasible explanation of the observed directional biases in depth judgment therefore may be that novices over-estimate stroke depth because of their non-familiarity with the effect of air resistance upon shuttle flight whereas experts, consistent with the systematic under-estimation of landing position evident in other film occlusion studies (e.g. Day, 1980), under-estimate stroke depth due to film presentation effects. Changes in the direction of depth error across the successive temporal occlusion conditions is generally non-systematic, although interestingly, the availability of more shuttle flight information (from t4 to t5) causes both groups to place their perceived landing position deeper relative to their earlier estimates.

(iv) Lateral versus Depth Errors Figure 29 provides comparison of the relative contributions of the lateral and depth error components to
Figure 29: Comparative absolute lateral and depth errors in the prediction of the shuttle landing position expressed as a function of the degree of temporal occlusion for the expert and novice groups in Experiment 1.

For the expert group lateral error is significantly greater than depth error on conditions t1, t2 and t3 whereas for conditions t4 and t5 the converse holds. For the novice group lateral error is significantly greater than depth error on t1 and t2 whereas depth error is significantly greater on t4 and t5.
the total error observed on each of the occlusion conditions. Analysis of this respective error data reveals the presence of a significant three-way interaction between the proficiency of the subjects, the temporal occlusion conditions and the error measures used ($F(4,212)=13.023, p<.05$) indicating that the relative magnitudes of the absolute lateral and depth error terms is at least partially dependent upon the subject's badminton proficiency and the extent of temporal stress in the task. Principally however, the post-hoc analyses (see Appendix G) reveal that lateral (directional) error is the major contributor to radial error for conditions in which only advance sources of information are available (viz conditions t1 – t3 for the expert group and t1 – t2 for the novice group) whereas depth error is the major contributor in those occlusion conditions (viz t4 and t5) where shuttle flight information is available. Consequently it would appear that advance information is most useful in resolving uncertainty about the depth (or 'force') of the forthcoming stroke whereas early shuttle flight information appears most useful in resolving uncertainty about the direction of the stroke.29

(v) Summary. To date then the following key findings emerge from the analyses of the temporal occlusion data in this first experiment.

29. This gives rise to the yet untested hypothesis that the majority of early anticipatory movements in racquet sports will be in the forward-backward direction rather than in the left-right direction (cf Alain &Proteau, 1978).
(a) Unlike previous studies, the contribution of directional and depth errors to total prediction accuracy have been clearly differentiated in these analyses. It appears that advance cues play a primary role in the resolution of depth uncertainty (i.e. uncertainty about the 'forcefulness' of the executed stroke) whereas early flight cues are most implicated in resolving the uncertainty related to the direction of the stroke (i.e. lateral error).

(b) Critical time periods for the extraction of specific directional and depth information have been implicated on the basis of the extent of error reduction over successive temporal occlusion intervals and these critical periods appear to be between 84 msec before and 84 msec after contact for directional information (i.e. t2 - t4) and in the last 84 msec preceding racquet-shuttle contact for depth information.

(c) Most importantly, consistent differences in prediction accuracy between expert and novice players have been observed on all of the occlusion conditions from t2 through to t5 and these differences appear to originate in the experts' superior capability for extracting both early lateral and depth information to improve performance.
in the time period from 168 msec before impact to 84 msec before impact (i.e. from t1 - t2). Although all information subsequent to t2 is not redundant (as performance for both groups continues to improve up to t4 and only t4 - t5 appears to provide totally redundant information) proficiency-related differences in prediction performance appear to be established early in the event sequence and are retained subsequently throughout the task.

The evidence presented here therefore supports existing film occlusion studies (e.g. Lyle & Cook, 1984; Salmela & Fiorito, 1979) in indicating the usefulness or importance of advance cues in stroke prediction and the greater capacity of experts to utilize these sources of information (e.g. Isaacs & Finch, 1983; Jones & Miles, 1978; Patrick & Spurgeon, 1978; Starkes & Deakin, 1984). The current study does however go beyond these existing studies in terms of both specifying the critical time periods for information extraction from the display and differentiating lateral and depth sources of prediction error and, in particular, in comparison with the widely-cited works of Jones and Miles (1978), provides a number of design advantages related to the use of a greater number of subjects, more clearly defined skill groups and more precise response measures. The current findings give support to those of Jones and Miles with respect to skill group differences being discriminable on the basis of prediction accuracy under limited preview (early occlusion) conditions but unlike the Jones and Miles study this study also indicates that these differences in prediction accuracy established early in the
stroke sequence persist across the whole range of temporal occlusion conditions, including the full display condition (t5). This observation of higher prediction accuracy at all but the first of the temporal occlusion conditions is more compatible with our earlier work (Abernethy & Russell, 1984; Experiment 1) with skilled cricketers although in that study the occlusion conditions were generally less stressful than those imposed in this study.

Having established that proficiency-related differences in the ability to extract display information exist, and thus having supported the first of the research hypotheses proposed, the next important issue becomes the more specific determination of what it is that allows the expert to display superior prediction accuracy to the novice. Specifically the concern is with whether the observed differences in performance on the temporal occlusion conditions are due to either

(a) general ('trait') differences between experts and novices in their ability to rapidly extract and analyze visual information from a briefly presented display

or (b) specific ('state') differences between experts and novices in the particular perceptual strategies they adopt to cope with the unique requirements of their sport environment.

If the differences in occlusion task performance are reflections of general visual-perceptual differences between expert and novice
Figure 30: Recall performance of the expert and novice groups on the unstructured alpha-numeric matrices in Experiment 1.

There are no significant differences between the two groups.
performers rather than being specifically related to differences in
sport-specific perceptual strategies (the 'trait' explanation) then
performance differences between the skill groups should persist across a
range of comparable visual perceptual tasks in which non-specific stimuli
are used. Although such an explanation appears unlikely in view of the
interaction between the temporal occlusion conditions and skill level
(i.e. the observation of skill group differences being dependent on the
specific occlusion conditions examined) this possibility was further
examined by comparing the performance of the two skill groups on the
recall of the unstructured letter matrices, presented as an addendum to
the film occlusion tasks.

When the recall performance of expert and novice badminton players
is compared on this task (see Figure 30) no differences in the
performance of the two groups are observed $F(1,53)=1.412, p>.05$.
Therefore, as was the case with the classical skill-specific memory
paradigm (e.g. Chase & Simon, 1973a; de Groot, 1965), the observed
performance differences between groups do not appear to reflect general
visual-perceptual characteristics but rather reflect differences
specifically related to the expert's sport-specific perceptual strategies
(or processing 'software').

Support for this conclusion (the 'state' explanation) can be
derived, in part, by comparing the response strategies for the two skill
groups as indicated by the absolute deviation of the landing prediction
responses from the court centre. Analysis of this measure revealed that,
on average, expert players make responses further from the court centre
Figure 31: Mean deviation of the prediction responses from court centre expressed as a function of the degree of temporal occlusion for the expert and novice groups in Experiment 1.

Significant differences exist between the groups on all conditions except t1. For the expert group significant differences exist between t2 and t3 and between t3 and t4. For the novice group significant changes occur from t2-t3, t3-t4 and from t4-t5.
than do novices \((F(1,53)=4.008, p<.05)\), although the observation of significant differences between the skill groups is dependent upon the extent of temporal information available to the subjects \((F(4,212)=4.887, p<.05)\) (see Figure 31).

In all four occlusion conditions in which some temporal occlusion of information takes place (viz t1 - t4) the expert players tend to choose more lateral placements of the predicted landing position than do novices - placements which, in the final analysis, are closer to the correct landing positions than those given by the novices. The novice subjects, on the other hand, consistently choose responses which are closer to court centre than are appropriate indicating a tendency for the novices to resolve the uncertainty facing them by making a 'best-bet' placement close to court centre. The expert's strategy of handling the high uncertainty conditions (most obviously t1 and t2) by making predictions which are directed away from the court centre equates much better with actual event probabilities than does the novice's strategy. These observed differences in both prediction performance (Figure 24) and task strategy (Figure 31) between the experts and novices therefore strongly indicate differences in the 'knowledge base' of sport-specific experiences which is used to guide the prediction performance of the two groups and support a specific 'software' explanation of proficiency-related differences in anticipatory performance.

As the ability to recognize and utilize situation-specific redundancy present in the opponent's display appears to be a discriminating feature of the expert performer then it appears logical to
Figure 32: Radial error in the prediction of the shuttle landing position as a function of the event occlusion conditions for the expert and novice groups in Experiment 1.

Significant differences exist between the groups on all conditions except e1 and for both groups error is significantly greater on conditions e1 and e2 than all other conditions. For the expert, but not the novice group, error is significantly greater on e1 than e2.
expect that the expert may be aware of some early redundant display features to which the novice is oblivious. Specifically it may be that the prediction performance differences of experts and novices arises as a consequence of the use of different anticipatory cue sources. This possibility is examined in the next section where the results of the event occlusion analyses are presented and differences in the specific anticipatory cues utilized by the two skill groups are considered.

**Event Occlusion Analyses**

(i) **Radial Error** Figure 32 presents the mean radial error for the expert and novice group on the five event occlusion conditions, plus the additional control condition (t3). Although significant main effects are observed for both the proficiency level ($F(1,53)=17.767, p<.05$) and the occlusion condition ($F(4,212)=63.073, p<.05$) factors in this analysis, the observation of prediction performance differences between the experts and the novices is dependent upon the specific cue occlusion which is provided ($F(4,212)=8.973, p<.05$). Specifically, the post-hoc analyses show that superior prediction accuracy is evident for the expert group under all event occlusion conditions with the exception of e1. In that case, when visibility of both the opponent's arm and racquet action are simultaneously prevented, the expert's landing position prediction is no different to that of the novice player.

As the importance of a specific cue to stroke prediction can be assessed by the extent to which prediction error is increased when that cue is occluded, the comparison of the error on each of the occlusion
conditions to that error evident under control conditions (e5) is an important one. For both the expert and the novice group, occlusion of either the arm and racquet (e1) or the racquet alone (e2) significantly disrupts prediction performance compared to control conditions (e5) whereas the occlusion of the players head (e3) or lower body (e4) induces no significant changes in prediction accuracy. This suggests, in keeping with observations from studies examining perception of comparable striking skills in field hockey (Lyle & Cook, 1984) and volleyball spiking (Neumaier, 1983), that the striking implement (in this case the racquet) and the most proximal limb (in this case the playing side arm) provide the most significant sources of information to aid in the anticipation of the forthcoming stroke. In badminton this information arises from the pre-contact movement of the racquet, and perhaps also to a lesser extent, from the arm holding the racquet. Conversely, cues available well away from the point of contact action, in this case cues provided specifically by the opponent's head and lower body, do not appear to provide advance information which can be used by either skill group to significantly improving stroke prediction.

When comparison is drawn between radial error under conditions where both the racquet and the arm are occluded (e1) and conditions where only the racquet is occluded (e2) some important skill group differences become apparent. For the expert group significantly lower prediction error is observed for condition e2 than e1 suggesting that the arm provides information which is of use in making landing position predictions, and that the arm is, in it's own right, a significant source
of relevant anticipatory information. For the novice group, however, radial error under the e1 and e2 conditions do not differ significantly indicating that, for them, the arm provides no additional anticipatory information beyond that carried by the racquet alone. It appears therefore that there may be some fundamental, proficiency-related differences in the usage of the arm as an anticipatory cue or at least some fundamental differences in the capability of experts and novices to extract information from this area of the display. Specifically experts appear capable of using information 'leaked' from the point of action (the racquet) to the closest limb segment (the arm) to aid in stroke prediction (after Carroll, 1972) whereas novices seem incapable of either extracting this information or being able to apply it meaningfully to the prediction task. These proficiency-related differences in cue usage become more apparent when the changes in radial error due to cue occlusion, rather than the absolute radial error values, are plotted as a function of specific cue occlusion (see Figure 33).

Because of the presence of significant differences in anticipatory performance between the two skill groups under conditions of no event occlusion (Figure 32), direct comparison of the relative importance of the different cue sources between skill groups necessitates control of these baseline differences. Such control is achieved by reporting the difference in prediction accuracy between each of the event occlusion conditions and the control condition (e5) thus deriving a measure which reflects the change in prediction error attributable to specific cue
Figure 33: Increases in radial error in the prediction of the shuttle landing position attributable to specific cue occlusion for the expert and novice groups in Experiment 1. (Increases are expressed relative to the control condition e5).

Significant differences exist between the groups on condition e1 only.
As was pre-empted from the previous analysis the subjects appear to place different reliance on the available sources of information, dependent upon their level of playing expertise ($F(3, 159) = 9.586, p < .05$). For experts both the racquet and the arm holding the racquet appear to contribute to the anticipation of the opponent's stroke whereas for the novices advance information appears to be extracted from the racquet alone. These differences in the role that information from the arm plays in the anticipation of the forthcoming stroke may well account for the differences in anticipatory capability between the two skill groups observed in the earlier temporal occlusion analyses and appears as clear evidence for the existence of fundamental differences in the visual selective attention of expert and novice performers. Interestingly, the experts, like the novices, nominated the racquet as the single most important anticipatory cue in their post-experiment estimates of their own cue usage, but did not verbalize any independent importance for information from the arm. This suggests that the experts use of this information from the arm in aiding anticipatory performance occurs quite automatically and is not the consequence of a consciously planned cognitive strategy.

Decomposition of the radial error measure of prediction accuracy into its lateral and depth components allows some indication of the role

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30. Performance on T3 rather than T5 could equally well be used as the control condition as no significant differences, and hence no evidence of distraction due to the event occlusion technique, are apparent between these two conditions. $F(1, 53) = 1.214, p < .05$
Figure 34: Absolute lateral error in the prediction of the shuttle landing position as a function of the event occlusion conditions for the expert and novice groups in Experiment 1.

Significant differences exist between the groups on conditions e3, e4 and e5. For both groups only conditions e1 and e2 differ from the control conditions.
that different specific cue sources play in the independent prediction of stroke direction and speed (force).

(ii) **Lateral Error** The absolute lateral error in prediction arising when different cue sources are selectively occluded is shown in Figure 34. As was the case with the radial error measure, the observation of significant prediction error differences between the expert and novice players depends upon what specific cue sources are occluded from the film trials ($F(4,212)=4.664, p<.05$). When vision of either the opponent's arm and racquet (e1) or the racquet alone (e2) is prevented experts show no difference in prediction capability to novices. In the conditions where these sources of information are available, but other cues (viz the player's head, lower body or an irrelevant background feature) are occluded, significant differences are consistently observed in favour of more accurate prediction of stroke direction by the experts.

In keeping with the earlier radial error analysis (Figure 33), the opponent's head and lower body appear to provide no useful information for either skill group for the prediction of stroke direction. Occlusion of either of these cue sources causes no increments in lateral error beyond control levels. Similarly, for both skill groups, occlusion of the racquet either by itself (e2) or in conjunction with the arm (e1), causes significant increments in lateral error beyond control levels implicating the racquet as a critical cue for the anticipation of forthcoming stroke direction. Again, most noticeably, the additional occlusion of the arm provided in condition e1 (relative to e2) causes a significant increase in lateral error for the expert group but not for the novice group, implicating a role for arm cues in the anticipation of
Increases in absolute lateral error in the prediction of the shuttle landing position attributable to specific cue occlusion for the expert and novice groups in Experiment 1. (Increases are expressed relative to the control condition e5).

Significant differences exist between the groups on condition e1 only.
stroke direction for the expert badminton players only. Differences in the respective capabilities of expert and novice performers to extract useful information from the arm may well contribute, at least in part, to the differences in ability to predict stroke direction which are observed under control conditions (i.e. either e5 or t3).

In order to account for these significant group differences in anticipatory performance under control conditions, and yet still gain an indication of relative cue usage between experts and novices, the event occlusion effects were also considered by determining the change in lateral error which was directly attributable to the occlusion of each specific cue source (see Figure 35). Figure 35 clearly demonstrates proficiency-related differences in cue usage, in keeping with the earlier predicted selective attention differences between expert and novices. Experts clearly attend to, and are capable of utilizing, arm information (in addition to racquet cues), in the prediction of stroke direction whereas novice players, on the other hand, appear incapable of utilizing the potential anticipatory information provided by the playing side arm to improve their anticipation of stroke direction.

A strong parallel appears to exist between both the radial and lateral error results, regardless of whether the error terms are expressed relatively (compare Figures 33 and 35) or absolutely (compare Figures 32 and 34), implicating a large and influential contribution of the lateral error component to the composite radial error measure. The role of the lateral error component can, however, be only fully assessed if the depth error component of radial error is also known and the two
Figure 36: Absolute depth error in the prediction of the shuttle landing position as a function of the event occlusion conditions for the expert and novice groups in Experiment 1.

Significant differences exist between groups on all conditions except e1. For the expert group e1 differs from all other conditions, whereas for the novice group none of the conditions are significantly different.
can be compared directly.

(iii) Depth Error When the absolute depth error in judgment is considered (Figure 36), a significant proficiency level x occlusion condition interaction is again observed ($F(4,212)=5.601, p<.05$), indicating that the generally superior prediction of landing position depth by the expert subjects ($F(1,53)=16.056, p<.05$) is not observed across all levels of cue occlusion. Specifically, although significantly lower depth errors are evident in the landing position predictions of expert subjects under all other conditions, when both the arm and racquet are occluded (e1) critical cues for depth judgment appear to be removed for the experts, causing their prediction accuracy to regress to the level of that of the novices.

In terms of the search for significant cue sources for depth prediction for the expert group, only the aforementioned condition e1 (i.e. the condition of both arm and racquet cues) differs from either of the control conditions (either e5 or t3), implicating that the arm, but not the racquet, contributes to the prediction of stroke depth. For the novices selective cue occlusion does not appear to impede depth prediction in any way with none of the event occlusion conditions returning depth errors significantly greater than those of the control condition. For the untrained subjects therefore none of the available anticipatory cues appear to be singularly important in the formulation of the depth prediction suggesting that the body action as a whole, rather than any specific segment, might be used as the basis for the perception of stroke force and the consequent prediction of stroke depth.
Figure 37: Increases in absolute depth error in the prediction of the shuttle landing position attributable to specific cue occlusion for the expert and novice groups in Experiment 1. (Increases are expressed relative to the control condition e5).

Significant differences exist between the groups on condition el only.
Direct analysis of the changes in depth error due to specific cue occlusion (see Figure 37) leads to the same conclusions being drawn. Quite obviously, yet again, the experts and novices vary in their respective use of the arm as a source of task-relevant information, in this case with respect to the anticipation of stroke depth. The experts' greater use of the arm as a cue source (a selective attention difference which has been already clearly demonstrated from lateral error data) provides access to information which can apparently aid in the assessment of stroke depth, and which again might account for the differences in depth prediction accuracy observed under the control conditions (see either Figures 27 or 36). The use of the arm as an advance source of information for predicting resultant stroke depth is a logical one biomechanically, in the sense that any alteration in stroke depth (as in a drop shot) will necessitate some alteration in arm speed and hence also often some concomitant changes in elbow positioning. In theory at last, the arm then provides potential depth cues which could be detected and utilized through a selective orientation of attention to that region of the display. The racquet itself, however, despite the orientation of both skill groups to it for directional information (see Figures 34 and 35), does not appear to provide a powerful source of anticipatory information for determining stroke strength, and subsequent shuttle landing depth.

(iv) **Lateral versus Depth Errors**. When the respective value of the different cue sources in resolving stroke directional and depth uncertainty are considered a number of interesting effects become
Figure 38: Comparative absolute lateral and absolute depth errors in the prediction of the shuttle landing position expressed as a function of the event occlusion conditions for the expert and novice groups in Experiment 1.

For both groups, lateral error is significantly greater than depth error at conditions e1, e2 and e4.
evident. Initially if the absolute lateral and depth errors are compared across both the event occlusion conditions and the level of badminton playing skill of the subjects (see Figure 38), a significant simple main effect is observed between the occlusions presented and the error measure derived ($F(4,212)=33.085, p<.05$) but in the absence of any higher order proficiency x error measure x occlusion condition interaction ($F(4,212)=0.314, p>.05$). This indicates that there are significant differences in the respective lateral and depth error components for the five event occlusion conditions and that the observation of this difference is consistent across both the expert and novice groups. Post-hoc analysis of this significant error measure x occlusion condition simple main effect reveals the presence of significantly greater lateral error than depth error for conditions $e1$, $e2$ and $e4$ ($p<.05$) with comparable lateral and depth errors on the other conditions. A clearer interpretation of this interaction between the cue(s) occluded and the lateral-depth error relationship can be gained from considering the changes in both these error terms which result when a specific cue is occluded (see Figure 39). In this way both skill group and inter-error differences in prediction performance under control conditions can be compensated for in the subsequent analysis.

With the use of difference scores rather than absolute error scores the respective lateral:depth error magnitudes are again shown to be influenced by the specific event occlusion condition ($F(3,159)=34.382, p<.05$) and unaffected by the skill level of the subject ($F(3,159)=0.264, p>.05$). Specifically the post-hoc analyses reveal that
Figure 39: Comparative increases in absolute lateral and absolute depth errors in the prediction of the shuttle landing position attributable to specific cue occlusion for the expert and novice groups in Experiment 1. (Increased in each case are expressed relative to the control condition e5).

For both groups significant differences exist between lateral and depth error on conditions e1 and e2.
under conditions where the racquet (e2) or the racquet plus arm (e1) are occluded, the magnitude of the lateral error in prediction significantly exceeds the depth error in prediction whereas under the conditions of either head (e3) or lower body (e4) occlusion the lateral and depth components of radial error are equal. This data therefore suggests that information derived from the arm and racquet is more important in resolving uncertainty about stroke direction than it is about stroke force (and hence landing depth) while information derived from the player's head or lower body is apparently not important in resolving uncertainty about either stroke direction or force.

The conclusion can be reached therefore that directional information is very segment-specific, apparently restricted to arm and racquet cues only, whereas information about the force of the developing stroke is less specific and can be obtained from a large number of possible sources. Consequently if a specific cue, such as the racquet, is occluded anticipatory information about stroke force to be used in depth prediction can be obtained from other sources (e.g. the upper body) whereas the same range of cue 'generality' is not available to support directional judgments. This suggestion of cue 'specificity' for directional/lateral predictions and cue 'generality' for depth predictions, although not previously advanced, seems commensurate with the limited existing sport-specific evidence examining the cues used in making two-dimensional predictions of object flight. Tyldesley, Bootsma and Bomhoff's (1982) preliminary eye movement data from subjects required to predict, from advance information only, either the direction or the direction plus height of soccer kicks at goal can be easily interpreted
### TABLE 6

Studies supporting the notions of cue specificity in directional prediction and cue generality in depth prediction

<table>
<thead>
<tr>
<th>Study</th>
<th>Cues for Horizontal (Directional) Prediction</th>
<th>Cues for Vertical (Depth) Prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tyldesley, Bootsma &amp; Bomhoff's (1982) study of prediction of soccer penalty kicks&lt;sup&gt;a&lt;/sup&gt;</td>
<td>lower leg (i.e., distal lever)</td>
<td>hip and upper body (i.e., more global sources)</td>
</tr>
<tr>
<td>Current study of prediction of badminton strokes&lt;sup&gt;b&lt;/sup&gt;</td>
<td>arm and racquet (i.e., distal lever)</td>
<td>arm, racquet, lower body and head (i.e., more global sources)</td>
</tr>
</tbody>
</table>

<sup>a</sup> Cue usage based on fixation location data.

<sup>b</sup> Cue usage based on event occlusion analyses.
within this framework (see Table 6).

(v) Summary. There appear to be fundamental differences in the cues that expert and novice badminton players use in an attempt to resolve, prior to shuttle flight, uncertainty about the forthcoming stroke direction and strength. Novices, in line with the suggestions made in many instructional manuals for racquet sports (e.g. see Brabanec, 1980, p. 33), appear to rely almost entirely upon the opponent's racquet to extract anticipatory information, and ignore (or at least extract no information from) cues arising from the opponent's playing side arm, head or lower body. Experts, on the other hand, whilst also extracting no information from the opponent's head and lower body, appear capable of extracting useful anticipatory information from not only the opponent's racquet but also from the arm holding the racquet. This additional arm information appears useful in terms of prediction of both stroke direction (as shown by the lateral error analyses) and stroke force (as shown by the depth error analyses).

The use of the arm as a source of anticipatory information appears logical if one considers the mechanics of stroke production and the relative time of occurrence of cues from the arm and racquet segments. Although the distal racquet cues are ultimately a more reliable and specific source of information than the more proximal arm segment cues the information from the arm action is available earlier than that from the racquet and therefore serves advantage as an early preparatory cue. Given that the arm may provide earlier anticipatory information than the racquet it is obviously tempting to also explain the expert's greater
ability to extract earlier information from the display, specifically in the period from t1 (168 msec prior to contact) to t2 (84 msec prior to contact) (see Figure 24), in terms of their use of the arm as a source of anticipatory information; a source which the novices apparently either do not attend to or are incapable of using. Direct proof of this relationship however would require the same event occlusion differences observed in this study to be also obtained when the display is occluded at t2 rather than the later t3 (contact point) occlusion which is currently used. Nevertheless this relationship between use of arm information and early anticipatory performance is supported circumstantially in Figure 20 in which it is apparent that substantial changes in arm but not racquet displacement occur between the occlusion points t1 and t2, thus implicating the arm as a more potent source of anticipatory information at this early period. In any case the event occlusion results demonstrate fundamental differences in the visual selective attention of expert and novice performers. These differences, in terms of actual information extraction from different sections of the opponent's display, have not been previously demonstrated in the sports science literature.

The evidence presented to date also indicates clear differences in the specificity of the information provided by different cue sources for the resolving of uncertainty related to stroke direction as opposed to stroke force. The resolution of uncertainty regarding stroke direction appears to be dependent on information provided by only specific segments or cues viz the racquet and, for the experts, the arm. Occlusion of either or both of these sources produces large increments in lateral
error, presumably because reliable information for anticipatory stroke direction cannot be generated from other sources. The resolution of uncertainty regarding stroke force, on the other hand, appears to be less cue-specific, with perhaps a large range of body segments providing potential information about landing position depth. Occlusion of any of the specific cue sources in isolation generally causes no major decrement in depth error, and as depth error is decreased as more anticipatory information becomes available (e.g. from t1 - t3 in Figure 27), it would appear that information for predicting stroke depth can be possibly gained from a wide range of areas in the display. The rate of translation of many of the body segments, especially the upper body, for example, may mirror the emerging force of the stroke but provide no cues as to stroke direction.

This observation of differential cue usage for lateral and depth predictions is compatible with predictions which can be derived from classical two-mode theories of visual perception (Held, 1970; Ingle, Schneider, Trevarthen & Held, 1967; Leibowitz & Post, 1982; Schneider, 1969). Specifically the prediction of stroke direction can be seen to be a cue-specific, requiring the use of high acuity, focal judgments (especially of events such as the angle of the racquet head at the point of contact) whereas the perception of stroke force and speed can be derived through ambient vision using information arising across the whole of the visual field. As the peripheral retinal detectors seem well designed to extract information regarding relative motion (Dichgans & Brandt, 1978; Paillard, 1980) a broader focus of visual attention, to use
Nideffer's (1976) terms, may be more appropriate for the prediction of landing position depth than is desirable for the prediction of object directionality. Details of a further study to examine the relative roles of focal and ambient vision in the prediction of emerging stroke direction and force are given in Appendix F.

Conclusions Regarding Proficiency Level Effects

To date the data derived from the analyses of the skill group main effects for both the temporal and event occlusion conditions provides support for the first two hypotheses proposed regarding proficiency-related differences in perceptual strategy. The temporal occlusion analyses support the conclusion that 'experts are more aware of the redundancies existing in the perceptual display than are novices and can therefore extract more information from earlier, advance cues than can novices'. The event occlusion analyses support the conclusion that 'experts attend to more relevant sources of information ... than do novices, with this effect being manifest in experts using different cues to those used by novices.'

Further additional support for both these hypotheses can be obtained by examining the maintenance of these proficiency effects across the different stroke types incorporated into the film task design. In the section that follows the contrasting effects of forehand v's backhand, cross-court v's down-the-line, and smash v's drop-shot stroke types will be considered within both the temporal and event occlusion frameworks in order to facilitate greater understanding of both the general extraction of anticipatory information in racquet sports and the generality of the
Figure 40: Radial error in the prediction of shuttle landing position for the forehand and backhand strokes expressed as a function of the degree of temporal occlusion for the expert group in Experiment 1.

Significantly higher error exists for the backhand strokes on conditions t1, t2 and t3. For both stroke types significant reductions in error occur from t1-t2, t2-t3 and t3-t4.
proficiency main effects already established.

(2) Analysis of Stroke Type Effects
(a) Forehand-Backhand Comparisons
Temporal Occlusion Analyses

A significant three-way interaction exists between the proficiency level of the subjects, the temporal occlusion condition presented and the stroke type, be it a forehand stroke or a backhand stroke \( F(4,208)=3.304, p < .05 \). This therefore necessitates simultaneous consideration of both the skill group and temporal occlusion condition factors in order to fully understand the relative perceptibility of the forehand and backhand strokes. For this reason comparison is made here, in turn, of (a) the forehand and backhand strokes independently for experts and novices and (b) the expert and novice groups independently for the two stroke types.

(i) Comparison of Forehand and Backhand Strokes for Experts  Figure 40 presents the respective radial errors in prediction by the expert group for the forehand and backhand strokes at each of the five levels of temporal occlusion. For this skill group greater overall mean radial error occurs for backhand trials than for the forehand trials \( F(1,19)=18.726, p < .05 \) but significant differences in prediction accuracy between the two stroke types are not observed across all of the temporal occlusion conditions \( F(4,76)=21.320, p < .05 \). Significant differences, in the direction of higher error on the backhand trials, are evident on conditions t1, t2 and t3 but not on conditions t4 and t5. It appears therefore that the experts find it more difficult to extract reliable
Figure 41: Radial error in the prediction of the shuttle landing position for the forehand and backhand strokes expressed as a function of the degree of temporal occlusion for the novice group in Experiment 1.

Significantly higher error exists for the backhand strokes on conditions t1, t2 and t3. For the forehand strokes significant decreases in error occur from t1-t2 and from t2-t3 whereas for the backhand strokes significant decreases occur from t2-t3 and from t3-t4.
advance information for the backhand strokes but once shuttle flight information is available the landing position of both stroke types are equally easy to determine. When changes in prediction accuracy across successive occlusion conditions are compared it is observed that the rates at which the experts gain information across time periods is comparable for both stroke types. It appears therefore that the principal difference between the perception of the two stroke types is merely the greater difficulty experienced in deriving initial information from early events in the backhand stroke sequence.

(ii) Comparison of Forehand and Backhand Strokes for Novices As was the case for the expert group, the novices display a greater overall mean radial error for backhand strokes than forehands ($F(1,33)=60.029, p<.05$) with the observed differences being dependent upon what specific temporal occlusion condition is examined ($F(4,132)=36.360, p<.05$) (See Figure 41). In parallel with the findings from the expert group, novices find it more difficult to extract advance information from backhand strokes (resulting in significant differences between stroke types at $t_1$, $t_2$ and $t_3$) but can predict landing positions for the two stroke types with equal accuracy once shuttle flight information is available (resulting in no differences on conditions $t_4$ and $t_5$). Most obviously, in comparing across successive temporal increments, shuttle flight information appears redundant for the prediction of forehand strokes whereas comparable flight information for the backhand strokes aids significantly in improving prediction accuracy beyond that possible from advance sources alone.

For both expert and novice players therefore, the most outstanding
Figure 42: Radial error in the prediction of the shuttle landing position for the forehand strokes expressed as a function of the degree of temporal occlusion for the expert and novice groups in Experiment 1.

Significant differences exist between the groups on all conditions except t1. For the expert group significant reductions in error occur from t1-t2, t2-t3 and t3-t4 whereas for the novice group only t2-t3 provides a significant reduction in error.
feature is the greater difficulty subjects experience in the extraction of advance information about the landing position of the backhand strokes. This empirical observation is in keeping with the subject's verbal reports of greater prediction difficulty for the backhand strokes and would appear to suggest that, at least for the stroke production of the subject used in this experiment, critical cues from the backhand are either better disguised or occur later in the stroke sequence than for the forehand equivalents. The backhand stroke production appears to be the result of a more distally-based 'wristy' action, and this may well allow stroke direction selection to be delayed to a later instant than occurs for the forehand, making advance prediction a more difficult undertaking.

(iii) Comparison of Experts and Novices on the Forehand Strokes

As one would expect from the proficiency-related differences in anticipatory performance discovered previously, there are some systematic skill group differences in the prediction of the respective landing positions of forehand and backhand strokes. When forehand strokes are considered (see Figure 42) the experts display significantly less error overall than the novices ($F(1,52) = 29.672, p < .05$) although the observation of significant between-group differences is contingent upon the specific temporal occlusion provided ($F(4,208) = 5.489, p < .05$). Significant differences between the two skill groups exist on the forehands at all occlusion conditions except $t_1$ suggesting that the greater prediction accuracy of the expert originates in the time period from $t_1$ to $t_2$ - a period in which experts, but not novices, significantly reduce their radial error.
Figure 43: Radial error in the prediction of shuttle landing position for the backhand strokes expressed as a function of the degree of temporal occlusion for the expert and novice groups in Experiment 1.

Significant differences exist between the groups on all conditions except t1. For the expert group significant decreases in error occur from t1-t2, t2-t3 and t3-t4 whereas for the novice group significant decreases occur from t2-t3 and from t3-t4.
Across the occlusion conditions experts show consistent gains in prediction accuracy with each temporal increment from t1 through to t4, whereas, the novices' improvements are spasmodic improving significantly only in the period from 84 msec prior to contact (t2) up to contact (t3).

(iv) **Comparison of Experts and Novices on the Backhand Strokes**

When proficiency-related differences in the prediction of backhand strokes are examined (see Figure 43) expert players are again found to exhibit consistently lower overall mean error than the novices ($F(1,52)=25.514, p<.05$) with the occurrence of group differences being dependent upon the specific temporal occlusion task being examined ($F(4,208)=6.522, p<.05$). As was the case with the forehand strokes, superior prediction accuracy is evident for the experts on all occlusion conditions except t1 with this prediction superiority for the expert group being apparently established in the period t1 - t2, and then maintained in a remarkably parallel fashion throughout the remaining occlusion conditions.

Therefore, irrespective of the forehand-backhand stroke type, experts display a capability for extracting advance information in the period t1 - t2 which can be used to enhance their prediction accuracy - information which the novices either do not attend to or do not have sufficient experience or cognitive schemas to utilize. These systematic differences in the time of extraction of critical anticipatory information are in keeping with the main effects for proficiency established earlier (e.g., see Figure 24) and indicate consistent differences in the ability of experts and novices to recognize and utilize redundancy inherent in the
Figure 44: Radial error in the prediction of the shuttle landing position for the forehand and backhand strokes as a function of the event occlusion conditions in Experiment 1.

Significant differences exist between the stroke types on all conditions. For both stroke types both $e_1$ and $e_2$ differ significantly from the control condition $e_5$. 
Figure 45: Increases in radial error in the prediction of the shuttle landing position attributable to specific cue occlusion for the forehand and backhand strokes for the expert group in Experiment 1. (Increases are expressed relative to the control condition e5).

Significant differences exist between the groups on condition e2 only.
early perceptual display.

**Event Occlusion Analyses**

The search for differences in the specific cues used by experts and novices in the respective predictions of forehands and backhands proceeds, as did the temporal occlusion analysis, by independent comparisons of the stroke types for the two different skill groups and of the skill groups for the two different stroke types. Preliminary analysis of radial error for all of the event occlusion conditions, including the control conditions e5 and t3, indicates that only the cues occluded in e1 and e2 (i.e. the racquet and possibly also the arm) appear to provide significant sources of information for the prediction of both forehand and backhand strokes (see Figure 44), but this interpretation may be dependent on the expertise of the subjects being examined. In the sections which follow the relative importance placed on different cue sources by the two skill groups is assessed using event occlusion difference scores (i.e. by determining the changes in error directly attributable to cue occlusion) and only prediction performance differences based on the composite radial error term are considered.

(i) **Comparison of Forehand and Backhand Strokes for Experts**

When the change in radial error due to cue occlusion is compared for the expert subjects between the forehand and backhand strokes (see Figure 45) no main effect for stroke type is observed ($F(1,19)=0.522, p>.05$) but there are significant differences apparent between the stroke types on some of the event occlusion conditions ($F(3,57)=3.634, p<.05$). A significant difference exists in the change in radial error attributable
Figure 46: Increases in radial error in the prediction of the shuttle landing position attributable to specific cue occlusion for the forehand and backhand strokes for the novice group in Experiment 1. (Increases are expressed relative to the control condition e5).

For the backhand strokes, unlike the forehand strokes, significant differences exist between e1 and e2.
to occlusion of the racquet alone (condition e2) for the two stroke types - the racquet itself being an apparently more important cue for the prediction of forehand stroke outcomes than backhand stroke outcomes. For the forehand stroke the racquet appears to be the single most important source of anticipatory information (e1 and e2 inducing greater error than e3 and e4, but not themselves differing) whereas for the backhand stroke arm information appears most critical (e1 having significantly greater error than all other conditions including e2). Most noticeably there is a significant reduction in the utility of racquet information in the perception of backhand strokes by the experts with some concomitant indications of a wider range of cue sources being employed in order to reliably 'construct' this particular stroke type.

(ii) Comparison of Forehand and Backhand Strokes for Novices. Similar comparisons of cue usage for novice players (Figure 46) again reveal an interaction between the observance of forehand-backhand differences and the specific cue occlusion conditions being considered ($F(3,99)=3.383, p<.05$). For the forehand strokes the racquet appears to be the principal source of anticipatory information, the conditions e1 and e2 inducing comparable levels of radial error. For the backhand strokes the racquet, and also surprisingly, the arm, appear to be used by the novices as the basis for predicting the shuttle's ultimate landing position. Although not strong, the available evidence, if anything, therefore implicates the use of a wider range of cues for backhand stroke prediction than forehand stroke prediction.

(iii) Comparison of Experts and Novices on Forehand Strokes
Figure 47: Increases in radial error in the prediction of the shuttle landing position attributable to specific cue occlusion for the forehand strokes for the expert and novice groups in Experiment 1. (Increases are expressed relative to the control condition e5).

Significant differences exist between the groups on conditions e1 and e2.
Overall experts show greater increases in radial error attributable to occlusion of display cues than do novices ($F(1,52)=4.947, p<.05$) but these proficiency-related differences are only evident for some of the four cue occlusions presented ($F(3,156)=9.250, p<.05$). For both skill groups occlusion of either the racquet and the supporting arm (e1) or the racquet alone (e2) produce significantly greater error than occlusion of either the opponent's head (e3) or lower body (e4) (see Figure 47) with, on both these critical cue occlusions, the expert's performance being impaired to a greater extent than the novice's. The expert group furthermore, unlike the novice group, show a significant increase in radial error directly attributable to the occlusion of arm information, again indicating a greater orientation of the expert group to the information available from this particular cue source. For the prediction of forehand strokes therefore, expert performer appears to use cues arising from both the arm and the racquet action whereas novices rely on racquet information alone suggesting, as did the earlier proficiency main effects analyses, that the ability to extract advance information from the arm holding the racquet is a critical 'software' difference between the expert and novice racquet sport player.

(iv) Comparison of Experts and Novices on Backhand Strokes

When the skill groups are compared on backhand rather than forehand strokes some different patterns of cue usage emerge (see Figure 48) with no systematic differences between the experts and novices either overall ($F(1,52)=1.097, p>.05$) or on any of the specific occlusion conditions ($F(3,156)=2.286, p>.05$). For both groups different display features are not treated equally importantly in terms of their usefulness as sources
Figure 48: Increases in radial error in the prediction of the shuttle landing position attributable to specific cue occlusion for the backhand strokes for the expert and novice groups in Experiment 1. (Increases are expressed relative to the control condition e5).

For both groups e1 produces significantly greater error than all other conditions.
of anticipatory information. The occlusion of both arm and racquet (e1) significantly impairs prediction accuracy more than the occlusion of the racquet alone (e2) which in turn causes significantly greater radial error than either head (e3) or lower body (e4) occlusion. Furthermore the occlusion of vision of the opponent’s lower body for this stroke type also induces significantly greater error than occlusion of vision of the opponent’s head, implicating this region as also potentially useful in the ultimate anticipation of the body position of backhand strokes. It appears then that for these strokes, unlike the forehands, prediction proceeds in a similar manner for both expert and novice players with information being accumulated from the racquet, the arm, and to a lesser extent, from the lower body. All subjects, irrespective of badminton playing proficiency, appear to use a wider range of less specific cues in the anticipation of backhand than forehand strokes.

Conclusions Regarding the Relative Predictability of Forehand and Backhand Strokes

Both skill groups find the backhand a more difficult stroke from which to extract advance information (see Figures 40 and 41) and this appears to be a consequence of the absence of any single cue source which provides reliable prediction information regarding the backhand (see Figures 45 and 46). Whereas for the forehand strokes there appears to be single specific segments (viz the arm and especially the racquet) which provide reliable advance information (and which therefore when occluded induce large increments in prediction error) for the backhand strokes there appears to be no comparable, singularly dominant source of reliable
information. Rather, information to aid prediction of the backhand strokes needs to be 'constructed' from a wider range of less reliable cues (viz the arm, racquet and lower body) implicating a broader range of cue usage than occurs for the forehands - a situation comparable to that observed previously in terms of the range of cues used in the making of respective directional and force judgements. Overall occlusion of specific cues for the backhand strokes results in decreased radial error increments relative to the forehand strokes, but with a larger range of display cues being affected.

For both stroke types experts appear capable of extracting advance information in the time period from 168 msec before contact (t1) to 84 msec before contact (t2) which novices are incapable of utilizing (see Figures 42 and 43), and this is consistent with the skill group main effects seen previously (e.g. see Figure 24). For forehand strokes these differences are apparently due to the expert's capability of extracting useful information from the arm, whereas the novices do not appear to utilize this cue (Figure 47). For backhand strokes no apparent differences in perceptual strategy are evident (both groups appear to use the arm, racquet and, to a lesser extent, lower body cues) and therefore it would appear that the observed performance differences must be largely due to the expert's ability to extract more information from these same cue sources (see Figure 48).

Cross-Court - Down-Line Comparisons

Comparison of cross-court and down-the-line stroke types allows many
Figure 49: Radial error in the prediction of the shuttle landing position for down-line and cross-court strokes as a function of the degree of temporal occlusion in Experiment 1.

Significant differences exist between the stroke types at t1 only. For down-line strokes radial error decreases significantly from t2-t3 and from t3-t4 whereas for cross-court strokes significant changes occur from t1-t2, t2-t3 and from t3-t4.
of the differences in directional prediction examined previously (e.g. see Figure 25) to be re-evaluated.

**Temporal Occlusion Analyses**

When the radial error associated with the prediction of strokes with cross-court and down-the-line destinations are compared (see Figure 49) an interaction between the stroke's direction and the condition of temporal occlusion emerges \( (F(4,208)=10.802, p<.05) \). Post-hoc analysis of this interaction reveals the existence of significantly greater prediction error for cross-court strokes than down-the-line strokes \( (p<.05) \) when the display is occluded at \( t1 \) (i.e. 168 msec prior to racquet-shuttle contact) with no differences between these stroke types evident at any of the other temporal occlusion points. The general overall indication therefore is that advance information regarding down-the-line strokes can be extracted earlier than can information of use in the prediction of cross-court strokes.

It is of considerable interest to now ascertain whether these differences in radial error observed between the two stroke types on condition \( t1 \) are a result of greater difficulty in extracting early information regarding the direction or force of cross-court strokes, or some combination of these two prediction components. This question can be examined by determining whether the lateral or depth component of the radial error term makes the greater contribution to the differentiation of the prediction performance for the two stroke types on condition \( t1 \).

Independent analysis of the absolute lateral (Figure 50) and
Figure 50: Absolute lateral error in the prediction of the shuttle landing position for down-line and cross-court strokes as a function of the degree of temporal occlusion in Experiment 1.

Significant differences exist between the stroke types at t1, t2 and t3. For down-line strokes significant changes occur from t2-t3 and from t3-t4 whereas for cross-court strokes significant changes occur from t1-t2, t2-t3 and from t3-t4.
Figure 51: Absolute depth error in the prediction of the shuttle landing position for down-line and cross-court strokes as a function of the degree of temporal occlusion in Experiment 1.

Significant differences exist between the stroke types at t2, t3, t4 and t5. For down-line strokes a significant decrease in error occurs from t2-t3 whereas for cross-court strokes significant changes occur from t1-t2, t2-t3 and from t3-t4.
absolute depth error components (Figure 51) indicates that the
differences in prediction error between the cross-court and down-the-line
strokes at t1 is due to a greater lateral error component in the cross-
court strokes. For the absolute lateral error measure, cross-court
strokes show greater error than down-the-line strokes on occlusion
conditions t1, t2 and t3 (F(4,208)=10.309, p<.05) whereas, in contrast, on
the absolute depth error measure, the down-the-line strokes contribute
greater error than the cross-court strokes at both occlusion times t2 and
t3 (F(4,208)=3.202, p<.05). The resultant combination of these two error
components is the greater radial error for the cross-court strokes at
condition t1 only (Figure 49).

As it is the prediction of direction which is of particular interest
in the comparison of the two stroke types greatest attention should
probably be paid in this case to the absolute lateral error analysis
(Figure 50) - an analysis which reveals significantly greater error for
the prediction of cross-court shots under all conditions where shuttle
flight information is not available (i.e. t1 - t3). It appears
reasonable to conclude on the basis of this data that advance directional
information is far more difficult to extract for cross-court strokes than
for down-the-line strokes and this is possibly because the magnitude for
cross-court angular variation is greater than that for down-the-line
strokes. The final cross-court angle produced will be somewhat dependent
on how late the change of racquet head angle necessary for the cross-
court stroke is introduced into the stroke's production.

In the overall consideration of prediction error it is apparent
Figure 52: Radial error in the prediction of the shuttle landing position for the down-line and cross-court strokes as expressed as a function of the degree of temporal occlusion for the expert group in Experiment 1.

Significant differences exist between the stroke types at t3 only. For both stroke types significant differences occur between t1-t2, t2-t3 and t3-t4.
however that the radial errors in judgment observed are dependent not only upon the stroke direction (be it cross-court or down-the-line) and the temporal occlusion condition applied, but also upon the skill level of the player making the prediction ($F(4,208)=7.180, p<.05$). For this reason the cross-court - down-the-line comparisons need to be made independently for the two skill groups in order to develop a clearer picture of the effect of these directional stroke types upon prediction accuracy.

(i) Comparison of Cross-Court and Down-Line Strokes for Experts For the expert subjects no main effect for stroke direction is evident ($F(1,19)=0.838, p>.05$) although a significant stroke x temporal occlusion interaction is present ($F(4,76)=2.980, p<.05$). This interactive effect (see Figure 52) is due to the presence of significantly greater error for cross-court strokes than for down-the-line strokes when the display is occluded right at the point of contact ($t3$), but at no other occlusion time. This difference would appear to be a non-systematic one with the general finding being that expert performers find both cross-court and down-the-line strokes equally easy to predict, indicating the absence of any form of perceptual bias or weakness related to either stroke type.

(ii) Comparison of Cross-Court and Down-Line Strokes for Novices Although a significant interaction between stroke direction and temporal occlusion is again observed for the novice group ($F(4,132)=15.684, p<.05$), unlike the case with the expert group, this effect appears to be a reflection of quite systematic differences in stroke type perceptibilities (see Figure 53). A significant difference in the
Figure 54: Radial error in the prediction of the shuttle landing position for down-line strokes expressed as a function of the degree of temporal occlusion for the expert and novice groups in Experiment 1.

Significant differences exist between the groups on all conditions except t1. For the expert group significant reductions in error occur from t1-t2, t2-t3 and from t3-t4 whereas for the novice group significant changes occur only from t2-t3 and from t3-t4.
Figure 53: Radial error in the prediction of the shuttle landing position for the down-line and cross-court strokes expressed as a function of the degree of temporal occlusion for the novice group in Experiment 1.

A significant difference exists between the stroke types at condition t1. For the down-line strokes significant reductions in error occur from t2-t3 and from t3-t4 whereas for the cross-court strokes significant changes occur from t1-t2, t2-t3 and from t3-t4.
predictability of cross-court and down-the-line strokes is evident at t1 in favour of more accurate prediction of down-the-line strokes, although these differences disappear at all subsequent occlusion times. Novices therefore, unlike experts, experience greater difficulty in extracting early information of use in the prediction of cross-court than down-the-line strokes (explaining the simple main effects observed in Figure 49) and one could infer that this may be a consequence of difficulty in extracting information about stroke direction (see Figures 50 and 51).

(iii) Comparison of Experts and Novices on Down-the-Line Strokes

When the expert and novice groups are compared on strokes with down-the-line destinations (Figure 54) it becomes apparent that although experts have lower prediction error overall \(F(1,52)=27.348, p<.05\) the extent of the differences between the two skill groups is again contingent upon the specific temporal occlusion condition \(F(4,208)=16.538, p<.05\). Differences between the groups exist on all temporal occlusion conditions with the exception of t1 suggesting that the superior prediction performance of the experts becomes established somewhere in the period between 168 (t1) and 84 (t2) msec prior to racquet-shuttle contact. This suggestion is supported by comparison of the two groups' respective abilities to reduce prediction error across successive temporal occlusion conditions, the most marked difference being the ability of the experts to use advance information available between t1 and t2 which the novices are apparently incapable of utilizing. These early established differences in prediction capability then seem to remain across all subsequent temporal occlusion conditions.
Figure 55: Radial error in the prediction of the shuttle landing position for cross-court strokes expressed as a function of the degree of temporal occlusion for the expert and novice groups in Experiment 1.

Significantly lower radial error exists for the expert group on all conditions. For both skill groups significant reductions in error occur from t1-t2, t2-t3, and from t3-t4.
(iv) Comparison of Experts and Novices on Cross-Court Strokes

For the cross-court strokes (see Figure 55) there is no interaction between the subject's skill level and the temporal occlusion conditions employed ($F(4, 208) = 2.223, p > .05$) with the expert performers displaying superior prediction accuracy across all of the occlusion conditions ($F(1, 52) = 18.590, p < .05$). A significant main effect for occlusion conditions is present ($F(4, 208) = 154.071, p < .05$) and this is due to significant gains in prediction accuracy being made with each increment of temporal information from $t_1$ through to $t_4$ for both groups. These results support the notion that the cross-court stroke, unlike the down-the-line stroke, involves consistent uncertainty across virtually the total production of the skill, with experts apparently capable of extracting more accurate prediction information across all of these occlusion conditions. The important subsequent issue now obviously becomes how these proficiency-related differences in the prediction of these two stroke types arises and this therefore requires examination of the corresponding event occlusion results.

Event Occlusion Analyses

The occlusion of specific cue sources (see Figure 56) causes consistently greater prediction error for cross-court strokes than down-the-line strokes across all of the event occlusion conditions, including the control condition $e_5$ ($F(1, 52) = 35.461, p < .05$). $^{31}$ Although no previous

$^{31}$ A significant stroke type $\times$ occlusion condition interaction was also found ($F(4, 208) = 14.443, p < .05$) but the post-hoc analysis showed that this effect was due to differences within rather than between the two stroke types.
Figure 56: Radial error in the prediction of the shuttle landing position for down-line and cross-court strokes as a function of the event occlusion conditions in Experiment 1.

Error for cross-court strokes is significantly greater on all occlusion conditions except t3.
differences in radial error between the two stroke types had been observed with a contact point occlusion (see condition t3 in Figure 49) the observation of systematic differences on the control condition e5 here necessitates the use of relative rather than absolute error scores in all remaining direct comparisons between the two stroke types.

When comparisons are made across the occlusion conditions but within the same stroke type it becomes apparent that for the down-the-line strokes the only significant source of anticipatory information is the racquet (conditions e1 and e2 differing from all other conditions but not from each other) whereas for the cross-court strokes both the racquet and the supporting arm seem important (e1 having greater prediction error than e2 which also differs significantly from all other conditions). For both strokes the player's head and lower body do not provide significant information to aid in stroke prediction supporting a contention made earlier that the prediction of stroke direction is obtained from very specific segmental sources viz the opponent's racquet and to a lesser extent the supporting arm. Further analysis reveals that the relative importance of these two cue sources varies according to not only the stroke type being observed but also with respect to the proficiency of the subject. Consequently the stroke type x skill group interactions for the event occlusion difference scores need to be examined in the same manner as the temporal occlusion effects were previously.

(i) **Comparison of Cross-Court and Down-the-Line Strokes for Experts**

In the absence of a main effect for stroke direction \([F(1,19)=0.003, p<.05]\) there is a significant interactive effect between
Figure 57: Increases in radial error in the prediction of the shuttle landing position attributable to specific cue occlusion for down-line and cross-court strokes for the expert group in Experiment 1. (Increases are expressed relative to the control condition e5).

Significant differences exist between the stroke types on condition e1 only.
Figure 58: Increases in radial error in the prediction of the shuttle landing position attributable to specific cue occlusion for down-line and cross-court strokes for the novice group in Experiment 1. (Increases are expressed relative to the control condition e5).

Significant differences exist between the stroke types on condition e1 only.
the stroke direction and the specific event occlusion conditions 
\( F(3,57) = 7.282, p < .05 \) for the expert group (see Figure 57). The arm and 
racquet together (e1) apparently contribute more to the perception of 
cross-court strokes than down-the-line strokes (\( p < .05 \)) with no 
differences being evident in the relative importance of any of the other 
cues to the prediction of the two stroke types. For expert players 
therefore cues derived from the arm appear to be of greater use in the 
prediction of cross-court than down-the-line strokes supporting the 
contention made previously from the overall comparison of the two 
directional stroke types (Figure 56).

(ii) Comparison of Cross-Court and Down-the-Line Strokes for Novices

For the novice group a significant main effect in favour of lower error 
for down-the-line strokes is apparent when the change in radial error due 
to specific cue occlusion is plotted (Figure 58) \( F(1,33) = 8.629, p < .05 \), 
but the relative importance of the different cue sources varies for the 
two stroke types \( F(3,99) = 10.439, p < .05 \). The most predominant effect is 
again, as it was for the expert group, the observation of a significantly 
greater reliance on the cues occluded in condition e1 (i.e. arm plus 
racquet) for cross-court stroke prediction, with no observed differences 
on condition e2 (i.e. racquet alone), implicating a dominant role for 
arm-based cues in the prediction of cross-court strokes. A possible 
exploration of this effect is that in the cross-court strokes the elbow 
(and therefore the arm) position alters in proportion to stroke 
direction, thereby providing a valuable source of anticipatory 
information, whereas in the down-the-line strokes the elbow position 
remains relatively constant and therefore does not act as a useful or
Figure 59: Increases in radial error in the prediction of the shuttle landing position attributable to specific cue occlusion for down-line strokes for the expert and novice groups in Experiment 1. (Increases are expressed relative to the control condition e5).

Significant differences between groups occur on conditions e1 and e2.
reliable source of advance information. Interestingly the presence of arm information may actually detract from the prediction of down-the-line strokes. For both skill groups a slightly, but not significantly, greater change in prediction error occurs for occlusion of the racquet only (e2) than for the racquet and arm (e1) implicating the arm as a possible source of unreliable or deceptive information for down-the-line stroke prediction.

(iii) Comparison of Experts and Novices on Down-the-Line Strokes

Figure 59 shows for experts and novices the changes in radial error which are attributable to specific cue occlusion in down-the-line strokes. Overall the occlusion of specific display features impairs the prediction accuracy of experts more than novices ($F(1,52)=7.861, p<.05$) although the extent of this impairment depends upon what specific cue is occluded ($F(3,156)=5.523, p<.05$). Significantly greater increases in radial error are evident for expert performers on the conditions where the racquet (e2) or the racquet and arm (e1) are occluded but no differences between the skill groups are evident with respect to the occlusion of visibility to either the opponent's head (e3) or lower body (e4). For the expert group the relative importance of the cues is such that e1 and e2 are more important than e3 and e4 ($p<.05$), but are not themselves different, again implicating the principal importance of racquet cues in the anticipation of the landing position of down-the-line strokes. For the novice group no significant differences are evident between any of the four occlusion conditions such that no single cue appears to predominate in the novice's attempts to predict down-the-line strokes. Clearly for these particular
Figure 60: Increases in radial error in the prediction of the shuttle landing position attributable to specific cue occlusion for cross-court strokes for the expert and novice groups in Experiment 1. (Increases are expressed relative to the control condition e5).

Significant differences exist between the groups on condition e1 only.
strokes the experts are more able to utilize the available racquet information than are the novices.

(iv) **Comparison of Experts and Novices on Cross-Court Strokes.** For the cross-court strokes (see Figure 60) there are again differences between the relative importance placed by experts and novices on some, but not all, anticipatory cue sources \( F(3,156)=3.827, p<.05 \). Differences between the groups exist upon condition e1 only with the experts showing a greater reliance on the arm and racquet cues than do the novices. As no proficiency-related differences are evident at e2 this indicates that the major difference between skill groups in the perception of cross-court strokes is a greater reliance by the experts upon information arising from the arm. Comparison of the occlusion condition effects within the skill groups indicates that although both skill groups rely upon the racquet and the supporting arm as critical cues for the prediction of cross-court strokes, it is the greater relative importance assigned to the arm information by the expert performer which appears as the discriminating characteristic.

**Conclusions Regarding the Relative Predictability of Cross-Court and Down-Line Strokes.**

Experts appear capable of predicting the landing position of cross-court and down-the-line strokes, from viewing of early cues, with equal proficiency (see Figure 52) although the prediction of the two stroke types is based on different cues. Down-the-line strokes are predicted from racquet cues only whereas for cross-court strokes the supporting arm, in addition to the racquet, provides advance information which can
Figure 61: Hypothesized relationship between the ability to extract advance information and the proportion of down-line:cross-court judgmental errors made by expert and novice performers at the different occlusion times.

- **OCCLUSION TIME T1**
  - Player can still produce either stroke direction.
  - Neither arm nor racquet provide reliable anticipatory information.

- **OCCLUSION TIME T2**
  - Player is committed to crosscourt stroke production.
  - Arm but not racquet provides reliable anticipatory information.

- **OCCLUSION TIME T3**
  - Contact is made with the shuttle with racquet head angle ensuring a cross-court stroke.
  - Both arm and especially racquet provide reliable anticipatory information.
be used in resolving directional uncertainty (Figure 57).

Novices experience greater difficulty with the extraction of early advance cues regarding cross-court stroke occurrence as opposed to down-the-line stroke occurrence (Figure 53) and this appears to be a consequence of their inability to extract the same degree of advance information from the arm for cross-court strokes as do experts (Figure 60). Because of the novice's inability to extract substantial early cues signalling cross-court stroke occurrence the differentiation of cross-court and down-the-line strokes becomes a delayed and somewhat biased process. Until reliable cues are available indicating the initiation of a cross-court stroke the novice's directional judgment appears to default to that of a down-the-line judgment. Consequently as information extractable by the novices to indicate cross-court stroke initiation may not become available until some 84 msec prior to contact time ($t_2$) any earlier occlusion of the display (viz at occlusion condition $t_1$) leads to directional judgments which will have a greater relative frequency of cross-court than down-the-line errors (see Figure 61). Although novices use similar cues to experts (Figures 57 and 58) their inferior prediction performance seems to be a consequence of extracting less information from the racquet in the perception of down-the-line strokes (Figures 54 and 59) and less information from the supporting arm in the perception of cross-court strokes (Figures 55 and 60).

Overall however, the comparisons of cross-court and down-the-line strokes reveal findings highly compatible with those gained from the proficiency main effects analysis performed earlier in that
(a) proficiency differences between experts and novices are primarily established early in the time period $t_1 - t_2$
and (b), in many cases, this anticipatory difference is apparently a consequence of the experts' greater reliance upon cues from the supporting arm and ability to extract greater amounts of information from the motion of the player's racquet.

Some stroke-specific differences have been observed however, and this justifies this examination of different stroke directions and necessitates similar examination of the effect of different stroke strengths (i.e. smash versus drop shots). This examination is made in the forthcoming section.

Smash - Drop-Shot Comparisons

Comparison of these stroke types of different strengths allows many of the differences in depth prediction examined previously to be re-evaluated (cf Figure 27).

Temporal Occlusion Analyses

When the radial error associated with the prediction of smash and drop-shots is compared (Figure 62), it becomes evident that the observation of significant differences in prediction performance between these two stroke types is dependent upon the extent of temporal information provided ($F(4,208)=9.421, p<.05$). Overall there is greater
Figure 62: Radial error in the prediction of the shuttle landing position for smash and drop shots as a function of the degree of temporal occlusion in Experiment 1.

Significantly lower prediction error occurs for the smash strokes on conditions t1, t2 and t5. For both stroke types significant differences exist between all adjacent temporal occlusion conditions.
radial error associated with the prediction of drop shots than smash strokes ($F_{(1,52)}=14.131, p<.05$) with significant differences evident under temporal occlusion conditions $t1$, $t2$ and $t5$. The greater difficulty experienced in accurately predicting the landing position of the slower strokes (i.e. the drop shots) is in keeping with findings from simple linear motion prediction tasks (e.g. Alderson, 1972; see Figure 11) where slower stimulus speeds are consistently found to be associated with greater temporal and spatial prediction error.

For both the smash and drop-shots each gain in temporal information from $t1$ through to $t4$ brings with it significant corresponding gains in prediction accuracy. Only for the smash strokes, however, is any further reduction in radial error evident when information in the period $t4 - t5$ is provided. For the drop-shots the provision of the additional shuttle flight information available in this period actually detracts from prediction performance, suggesting possible difficulties with monitoring the additional flight provided by the drop shots perhaps due to difficulties in either determining the court perspective or extracting reliable depth cues from the film display.

The poorer overall prediction accuracy for drop shots appears, not surprisingly, to be largely a consequence of the greater difficulty in extracting reliable depth rather than lateral information regarding the stroke's landing position. Specifically when the absolute lateral error is compared between these two stroke types (Figure 63), the extent of the error observed is dependent upon the temporal occlusion condition ($F_{(4,208)}=23.146, p<.05$) with differences being evident at $t1$, $t2$ and $t3$. 
Figure 64: Absolute depth error in the prediction of the shuttle landing position for smash and drop shots as a function of the degree of temporal occlusion in Experiment 1.

Significant differences exist between the stroke types at conditions t1, t2 and t5. For the smash strokes significant changes occur from t1-t2 and from t4-t5 whereas for the drop shots significant changes occur from t2-t3 and from t4-t5.
Figure 63: Absolute lateral error in the prediction of the shuttle landing position for smash and drop shots as a function of the degree of temporal occlusion in Experiment 1.

Significant differences in favour of lower error for the smash strokes exist at conditions t1, t2 and t3. For the smash strokes significant differences occur from t2-t3 and from t3-t4 whereas for the drop-shots significant changes occur from t1-t2, t2-t3 and from t3-t4.
For both stroke types absolute lateral error is reduced most, and hence directional information gained most, in the period from 84 msec before contact to 84 msec after contact (i.e. t2 - t4).

When the absolute depth error is compared between the smash and drop-shots (Figure 64), again a significant simple main effect for stroke type x temporal occlusion condition exists ($F(4,208) = 9.282, p < .05$) with the drop shots exhibiting significantly greater depth error at occlusion conditions t1, t2 and t5. For both of these stroke types the prediction of stroke depth appears to be established primarily on the basis of advance cues (with drop shots presenting more deceptive depth information than is provided in the smash) with subsequent shuttle flight information only acting to confuse the pre-established depth prediction.

Therefore, although the effects are perhaps not as clear as one would predict, for the determination of stroke direction (i.e. cross-court v's down-the-line stroke types) the most discriminating component is the lateral error measure whereas for the determination of stroke strength (i.e. smash shots v's drop-shots) the most discriminating component appears to be the depth error measure. Further, the determination of stroke strength appears to be established from advance information only whereas the determination of stroke direction continues well into the shuttle flight stage and is resolved largely in the period t3 - t4. For stroke direction therefore, the period of maximum resolution of lateral error is from t3 - t4 (see Figure 50) whereas for stroke strength the period of maximum resolution of depth error is from t2 - t3 (see Figure 64) implicating that the principal discrimination of
Figure 65: Radial error in the prediction of the shuttle landing position for smash and drop shots expressed as a function of the degree of temporal occlusion for the expert group in Experiment 1.

Significantly lower error exists for the smash strokes at conditions t2 and t3. For both skill groups significant reductions in error occur from t1-t2, t2-t3 and from t3-t4.
stroke strength comes from advance informational sources whereas the principal discrimination of stroke direction continues well into the shuttle flight stage. These implications regarding the respective critical time periods for the extraction of stroke strength and direction information are in keeping with the general conclusions reached earlier from the more detailed comparisons of lateral and depth error (cf Figure 29).

As has been the case with the other stroke type analyses (viz the forehand-backhand comparisons and the cross-court - down-the-line comparisons) understanding of the prediction of smash and drop-shots also requires a consideration of the skill level of the subject making the prediction - a significant three-way interaction existing between the proficiency level factor, the stroke force and the temporal occlusion conditions ($F(4,208)=3.411, p < .05$). This interactional effect necessitates the independent examination of the smash and drop-shot performances of the two skill groups.

(i) **Comparison of Smash and Drop Shots for Experts** Figure 65 presents the prediction performance of the expert group for the smash and drop-shots as a function of the level of temporal occlusion. No main effect for stroke type exists ($F(1,19)=1.048, p > .05$) but there is a significant interaction between the stroke type and the condition of temporal occlusion ($F(4,76)=3.060, p < .05$) due to lower drop-shot error on conditions t2 and t3. These differences are in the opposite direction to those observed previously (see Figure 62), and in the absence of a significant main effect for stroke type, justify the conclusion made
Figure 66: Radial error in the prediction of the shuttle landing position for smash and drop shots expressed as a function of the degree of temporal occlusion for the novice group in Experiment 1.

Significant differences in favour of lower error for smash strokes exist on all conditions except t4. For the smash strokes significant changes occur from t2-t3 and from t4-t5, whereas for the drop shots significant changes occur from t2-t3, t3-t4 and from t4-t5.
Figure 67: Radial error in the prediction of the shuttle landing position for smash shots expressed as a function of the degree of temporal occlusion for the expert and novice groups in Experiment 1.

Significant differences exist between the groups at t1 and t4. For the expert group significant reductions in error occur from t1-t2, t2-t3 and from t3-t4 whereas for the novice group significant changes occur from t2-t3 and from t4-t5.
earlier, with respect to the cross-court and down-the-line strokes, that there appears to be no systematic perceptual bias or stroke-type weaknesses in the prediction capacity of the expert player.

(ii) **Comparison of Smash and Drop Shots for Novices** The novice subjects, in contrast, again show a systematic perceptual weakness for one of the two stroke types; in this case the drop shot. Novices (see Figure 66) demonstrate a significant and systematic difficulty in extracting reliable prediction information from the drop-shot \((F(1,33)=28.495, p<.05)\) and this difficulty shows itself when the prediction has to be made either from advance sources alone (i.e. conditions t1 - t3) or from late shuttle flight cues (i.e. condition t5 but not t4). These inadequacies in the perception and prediction of the landing position of drop shots by the novice badminton players become even more evident when skill group comparisons are made independently for the two stroke types.

(iii) **Comparison of Experts and Novices in Smash Strokes** Although there are no overall group differences on the smash strokes (see Figure 67) \((F(1,52)=0.000, p>.05)\) differences between the groups exist for some of the temporal occlusion conditions \((F(4,208)=11.008, p<.05)\). When the display is occluded 168 msec prior to contact (condition t1) the radial error for the expert group is significantly greater than that for the novice group - a finding which is extremely difficult to explain, being contrary to all other data collected regarding the relative capabilities of experts and novices in extracting advance information. A significant difference in prediction accuracy also exists when the display is
Figure 68: Radial error in the prediction of the shuttle landing position for drop-shots expressed as a function of the degree of temporal occlusion for the expert and novice groups in Experiment 1.

Experts display significantly lower error on all occlusion conditions. For both groups, significant reductions in error occur from t1-t2, t2-t3 and from t3-t4.
ocluded 84 msec after contact with the radial error for experts in this case being, as expected, less than that for the novice group. Although differences also exist between the groups in terms of the gains in prediction accuracy made across successive temporal increments (experts reduce their prediction error significantly in all periods from t1 through to t4; novices reduce their prediction error significantly only in the periods from t2 - t3 and from t4 - t5), overall the prediction of smash stroke landing positions proceeds in a reasonably similar manner for both the experts and the novices.

(iv) Comparison of Experts and Novices on Drop Shots Unlike the smash strokes, the prediction of drop shots varies dramatically dependent upon the subject's proficiency (see Figure 68) with strong main effects for both the skill groups ($F(1,52)=36.356, p<.05$) and the temporal occlusion conditions ($F(4,208)=126.472, p<.05$). There is no interaction between these two factors in the case of the drop shots ($F(4,208)=1.752, p>.05$) demonstrating that the prediction accuracy of the experts is greater than that of the novices at all five temporal occlusion points. Apparently an important feature which discriminates between expert and novice badminton players is the respective capabilities of the two groups to predict the landing position of drop shots.

The clear distinction between the skill groups on the drop-shots but not on the smashes may be a consequence of the extent of prior relevant task experience the different subject groups bring to the test situation. For the smash strokes, the novice's prior experience with any other
Figure 69: Increases in radial error in the prediction of the shuttle landing position attributable to specific cue occlusion for smash and drop shots for the expert group in Experiment 1. (Increases are expressed relative to the control condition e5).

Significant differences exist between the strokes on occlusion conditions e1 and e2.
racquet sport or comparable overarm movement pattern (e.g., the volleyball spike) may be quite relevant to the prediction task resulting in an absence of skill group differences on this stroke type. For drop shots these same prior experiences for the novices are less likely to be relevant and this may lead to a task performance significantly worse than that of the expert group. Specifically the novices will be unfamiliar with the particular deception skills used in badminton and will be unfamiliar with the unique flight characteristics of the badminton shuttle—factors which take on greater importance in the drop shots than in the smash strokes.

To determine if these differences in the performance of the two skill groups on the different stroke types are a consequence of systematic differences in perceptual strategy the customary event occlusion analyses were also undertaken.

Event Occlusion Analyses

(i) Comparison of Smashes and Drop-Shots for Experts The changes in radial error due to the occlusion of specific cue sources in both the smash and drop-shots for experts are shown in Figure 69. Differences in radial error increments between the smash and drop-shots occur for the occlusion of some but not all specific cue sources ($F(3,57)=7.860, p<.05$), with significantly greater radial error increases for the drop-shots evident on conditions e1 and e2. These differences probably reflect either (a) a relatively greater overall reliance on racquet and arm cues for drop-shot prediction or (b) a greater ability of the subjects for the
Figure 70: Increases in radial error in the prediction of the shuttle landing position attributable to specific cue occlusion for smash and drop shots in the novice group in Experiment 1. (Increases are expressed relative to the control condition e5).

Significant differences exist between the strokes on occlusion conditions e1, e2 and e3.
smash strokes to compensate specific cue occlusion by using information available from other sources. For both stroke types prediction error under conditions where both the racquet and arm are occluded (e1) is significantly greater than error under conditions where only the racquet is occluded (e2) demonstrating the utility of both arm and racquet cues to the expert's prediction of both the smash and drop-shots.

(ii) Comparison of Smashes and Drop-Shots for Novices. As with the expert data, the novice group's data reveals a significant main effect for stroke type ($F(1,33)=25.873, p<.05$), attributable to greater radial error increments for the drop-shots, and a significant stroke type x event occlusion interaction ($F(3,99)=14.031, p<.05$), attributable to greater radial error increments for the drop-shots on conditions e1, e2 and e3 (see Figure 70). The novice therefore, like the experts, place greater emphasis upon racquet and arm cues in the prediction of drop-shots as opposed to smash strokes. The only difference apparent between these data and that for the experts is in terms of an additional greater reliance on information from the opponent's head in the prediction of drop-shots by novices but this, in all probability, is merely an artifact of the negative difference score recorded by the novice group under condition e3 for the smash strokes. (A negative difference score arises when the specific event occlusion condition has less error than the control condition).

(iii) Comparison of Experts and Novices on Smash Strokes. When the expert and novice groups are compared on their specific cue usage for smash stroke prediction (Figure 71) it is observed that the relative
Figure 71: Increases in radial error in the prediction of the shuttle landing position attributable to specific cue occlusion for smash shots for the expert and novice groups in Experiment 1. (Increases are expressed relative to the control condition e5).

Significant differences exist between the groups on condition e1 only.
importance placed on the available cue sources varies according to the skill level of the subjects \((E(3,156)=4.450,p<.05)\), with greater increments in radial error evident for the expert group on condition e1 only. For the expert group the relative importance of the cues presented in e1 is higher than that for all of the other conditions (with no significant differences being evident between either e2, e3 or e4) indicating that for this group the arm appears to provide the most powerful source of information regarding the landing position of the smash. For the novice group no single anticipatory cue appears more important than the others (no significant differences exist between the four conditions) suggesting that either the critical cue used by novices in smash stroke prediction is not one of the four manipulated in this experiment or, the more likely alternative, that a conglomerate of cues can be used for smash prediction and consequently that the removal of one cue can be compensated for through prediction derived from other cue sources.

(iv) Comparison of Experts and Novices on Drop-Shots. When skill group differences in the use of anticipatory cues for the drop-shot are considered (Figure 72) greater increments in radial error are found for the experts when both the arm and racquet are occluded \((E(3,156)=6.274,p<.05)\) with no differences under any of the other event occlusion conditions. For the expert group prediction of the landing position of drop-shots appears to be achieved through a combination of both racquet and arm cues, with the radial error increments due to arm and racquet occlusion (e1) being greater than those for occlusion of the
Figure 72: Increases in radial error in the prediction of the shuttle landing position attributable to specific cue occlusion for drop shots for the expert and novice groups in Experiment 1. (Increases are expressed relative to the control condition e5). Significant differences exist between the groups on condition e1 only).
racquet alone (e2), which are in turn greater than those attributable to either head (e3) or lower body (e4) occlusion. In contrast the novice's prediction appears to be achieved primarily through only racquet cues with no differences in prediction error being apparent between conditions e1 and e2. The major differences previously observed in the prediction of drop-stroke landing positions by experts and novices (see Figure 68) appears, therefore, to be, at least in part, a consequence of the expert's greater capacity to extract relevant information from the arm—a perceptual strategy which is logical if one considers the necessity of a slowed arm action in order to produce the decreased racquet head speed at contact point which is characteristic of the drop-shot. These proficiency-related differences in drop-shot perception are consistent with the skill group main effects observed previously (cf Figure 33).

Conclusions Regarding the Relative Predictability of Smashes and Drop Shots

Experts predict drop-shots and smashes with essentially equal proficiency (see Figure 65), utilizing in both cases racquet and arm information (Figure 69) in order to make these predictions. This perceptual consistency for the experts across stroke types is consistent with observations drawn from the comparison of cross-court and down-the-line strokes. Novices, on the other hand, experience considerable difficulty in predicting the landing position of drop-shots in comparison to smashes (Figure 66) and, although they utilize a number of specific cue sources in attempting to predict drop-shots (viz the racquet and the arm; Figure 70), the major problem novices experience would appear to reflect their absence of specific familiarity with the flight
characteristics of the badminton shuttle over different extents of stroke force. Skill group differences in prediction performance are most pronounced on drop shots (see Figure 68) and this appears, at least in part, to be due to the expert's systematically greater capacity for extracting information from the arm action, in addition to the more easily recognized information provided by the racquet (Figure 72).

General Conclusions Regarding Stroke-Type Effects

Although some differences in the skill group effects are evident when the different stroke types are analyzed, in the main the support for the first two of the three research hypotheses proposed at the commencement of this chapter, still remains. Specifically, within the variations provided by the different stroke types, the available evidence still strongly supports a superiority of the expert performer in the recognition of early information redundancy in the opponent's display (hypothesis 1) and a capability of the expert player to extract information from display sources (primarily the arm) which are not utilized by the novices (hypothesis 2).

Further examination of this second hypothesis relating to differences in cue usage and initial examination of the third hypothesis, relating to differences in information-processing rates between expert and novice performers, will be made in the next experiment in which visual search data are analyzed.
Figure 74: Eye movement recording configuration used in Experiment 2.
Figure 73: Eye movement recording apparatus used in Experiment 2.
Method

Subjects. Subjects were 15 expert badminton players and 16 novice badminton players, each of whom had also participated in Experiment 1. Twelve males and three females made up the expert group whilst the novice group consisted of 11 males and five females. As the groups used in this experiment were actually sub-sets of the groups used in Experiment 1 their demographic characteristics were similar to those reported earlier.

Apparatus A Polymetric Mobile V0165 Eye Movement Recorder was used to record the subject's visual search patterns as they performed the film occlusion tasks described in Chapter 4 and in Experiment 1. This particular model of eye movement recorder, which necessitates the use of a bite-bar to stabilize the recording apparatus upon the subject's head (see Figure 73) has a reported accuracy of 1° within horizontal and vertical ranges of +/- 10° (Young & Sheena, 1975a). The subjects' eye movements, appropriately calibrated to the film display, were recorded onto video-tape using an RCA Ultricon TC2014 UX low-light video camera coupled to a JVC HR-7600MS VHS video player-recorder and were simultaneously displayed onto a Sony PVM-1370QM Trinitron high resolution monitor placed out of the subjects' field of view (see Figure 74). The overall experimental setting is presented photographically in Figure 75.

Procedures. For each subject a waxen bite-bar was moulded and the eye movement recording apparatus fitted onto the subject's head as shown in Figure 73. The eye movement recorder was then calibrated for both position and linearity to ensure the fixation mark (a light spot
Figure 75: Overall experimental set-up used in Experiment 2.
reflected from the subject's left cornea) corresponded precisely to the subject's fixations upon different sectors of the viewing screen and this calibration was checked repeatedly throughout the course of the experiment. During the performance of the film task subjects were instructed to return their visual focus to the screen centre after the completion of each trial and on any occasion where this visual focus was not apparent from the monitored eye movement recorder output the film was stopped and re-calibration of the eye mark was performed. Standard calibration checks were made at each of the three rest intervals incorporated in the film task design. The bite-bar and eye movement recording apparatus were removed immediately upon the subject's completion of the film task.

**Analysis of Data** The visual search patterns used by each of the subjects in the performance of the film occlusion tasks were analyzed frame-by-frame using the VHS player-recorder described earlier as part of the data capture configuration. (This particular player-recorder provided the capacity for reliable frame-by-frame advancement of the video record avoiding the limitation inherent in many video play-back units where the noise bar is not cleared from the screen and sequential frames are not discretely located). For each of the 320 film trials per subject, data was extracted on:

(a) the number of frames between when the film trial commenced and when the first saccadic movement was made

(b) the number of frames between when the film trial finished (i.e. when the display was occluded) and when the eye made its last saccadic movement away from the screen
and (c) the number of frames, plus the location, of all fixations occurring during the film trial period.

These data were then coded onto a data collection record as shown in Appendix C-1. For the purposes of this analysis a fixation was operationally defined as any state in which the eye mark remained stationary (i.e. at the same location) for any period equal to, or in excess of, 3 frames (i.e. 120 msec). Fixation location information was recorded using the following locational codes, based on the arbitrary division of the display into discrete zones.

- r - fixations on racquet
- s - fixations on the shuttle during its outflight
- t - fixations on the trunk and body centre
- h - fixations on the head and face
- f - fixations on the legs and feet

The precision with which the eye movement recorder could determine the fixation locations prevented any finer division of the display and prevented, for example, the desirable discrimination between fixations on the forearm and fixations on the racquet head. Fixations on the screen during the inter-trial interval and prior to film trial commencement were also coded (using the symbol x), as were on-screen fixations after film occlusion (symbol y), and fixations which were either to an un-named region of the display or whose locations could not be clearly identified (e.g. due to calibration difficulties) were designated using the symbol n. The coded data for each subject was then entered as an independent

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32. It is not clear from other visual search studies which use either film or slide-presented displays (e.g. Bard & Fleury, 1976a; Bard et. al., 1980) how fixations which start prior to, but transcend, the trial duration have been, or should be treated.
**Figure 76:** Sample derivation of the visual search measures used in Experiment 2. (Example is based on Subject #01, trial #04).
input file on to the PDP 11/34 minicomputer, as used in Experiment 1.

Knowing the video sampling rate of 25 frames/second, this coded input data was then used to compute a series of dependent temporal measures of visual search using the fortran program 'badscan.for' (see Appendix C-2). The following dependent measures were derived for each trial:

**Visual Correction Time (VCT)** which was the time between when the film display first appeared and when the first saccadic eye movement to the new display was made.

**Dwell Time (DT)** which was the time the eye remained fixated upon the screen after the film trial had been completed and the display occluded.

**Number of Fixations (NF)** which was the number of the fixations made during the film trial, including fixations which commenced before the film trial but overlapped into the trial duration and fixations which do not end until after the film trial was completed.

**Mean Fixation Duration (FD)** which was the average duration of all fixations occurring during, or transcending the film appearance (i.e. the mean length of all fixations counted in the NF measure).

and **Percentage of Film Trial Time per Cue** (i.e. %r, %s, %t, %h, %f, %x and %n) which was the percentage of the actual film trial time which was spent at each one of the locations previously outlined.

An example of the calculation of each one of these dependent measures for a sample film trial is provided in Figure 76. On trials in which the visual search data could not be extracted from the video record, mean parameter values were supplied by taking the average value of the search characteristics used in performing the other trials of the same stroke and occlusion type (as with the missing data procedure used for the response accuracy measures in Experiment 1).
TABLE 7

Independent and dependent variables in Experiment 2

A. INDEPENDENT VARIABLES

Between Group Factors
- Proficiency (2 levels)
- Gender (2 levels)

Within Group Factors
(i) Occlusion Conditions
   - Temporal Occlusion Conditions (5 levels)
   - Event Occlusion Conditions (5 levels)
(ii) Stroke Types
   - Forehand - Backhand Strokes (2 levels)
   - Cross-court - Down-line Strokes (2 levels)
   - Smash shots - Drop shots (2 levels)
(iii) Replications
   - Stroke Type Replications (4 levels)

B. DEPENDENT VARIABLES

(i) Visual Correction Time (VCT)
(ii) Dwell Time (DT)
(iii) Number of Fixations (NF)
(iv) Mean Fixation Duration (FD)
(v) Mean Percentage of Trial Time Allocated to Each Cue Source
   - Racquet fixations (%r)
   - Shuttle fixations (%s)
   - Trunk fixations (%t)
   - Head fixations (%h)
   - Feet fixations (%f)
   - Screen Centre fixations (%x)
   - Not Determinable Locations (%n)
The computer program scanova.f or (Appendix C-4) was then used to select out the required independent and dependent variables for analyses of variance, as in Experiment 1. A list of these independent and dependent variables for this experiment are presented in Table 7.

In addition to the analyses of variance performed on these search pattern parameters the visual search pattern data were also analyzed in terms of the fixation duration distributions and in terms of generalities in the search sequence. The distribution of the obtained fixation durations, for different levels of the independent variables, were derived using the programs 'distrb.f or' and 'dist.f or' (Appendix C-5) and were plotted using the graphics capabilities of a Hewlett-Packard 7470A Plotter. Similarly the sequential dependencies in the observed fixation locations, in terms of the percentage of time each location precedes or is preceded by each and every other fixation location, was determined using the fortran program 'seqn4.out' (see Appendix C-6) and applied to independent comparison of the expert and novice skill groups. As in Experiment 1 all computations were performed on a DEC PDP 11/34 mini-computer and an alpha level of 0.05 was pre-selected for all relevant statistical comparisons.

Results and Discussion

(1) Response Accuracy Analyses

In order to directly compare the results of the eye movement recording analyses from this experiment with the results of the film occlusion analyses reported in Experiment 1 it is necessary to demonstrate that the performance on the film occlusion tasks of the smaller (n = 31) sample
Figure 77: Radial error in the prediction of the shuttle landing position as a function of the degree of temporal occlusion for the expert and novice groups in Experiment 2.

Significant differences exist between the groups on all occlusion conditions except t1. For the expert group significant decreases in error occur from t1-t2, t2-t3 and from t3-t4, whereas for the novice group significant changes occur from t2-t3 and from t3-t4.
currently used here mirrors that obtained from the larger \( n = 55 \) sample used in Experiment 1. For this reason the principal skill-group comparisons on the temporal and event occlusion conditions were re-computed for this smaller sample of subjects (using the dependent measure of radial error) and the results of this analysis are considered below.

**Temporal Occlusion Analysis**

Figure 77 displays the radial error in prediction as a function of the conditions of temporal occlusion for the expert and novice groups formed for Experiment 2. A significant interaction exists between the skill level of the subjects and the temporal occlusion condition used \( (F(4,116)=7.735, p<.05) \) with significantly lower prediction error evident for the expert group on all occlusion conditions from \( t_2 \) through to \( t_5 \); a statistical conclusion identical to that reached in Experiment 1 (cf Figure 24). Similarly, as was the case with the larger sample used in Experiment 1, the distinguishing characteristic of the expert group was again their capability to extract early advance information which allows their prediction accuracy to be significantly improved from occlusion time \( t_1 \) to occlusion time \( t_2 \).

**Event Occlusion Analyses**

Analysis of the prediction performance of the expert and novice groups under the event occlusion conditions (Figure 78) reveals significantly greater radial error for the novice group under all conditions except \( e_1 \), i.e. the condition where both the arm and racquet were occluded from visibility \( (F(4,116)=7.275, p<.05) \). For the expert group both the racquet
Figure 78: Radial error in the prediction of the shuttle landing position as a function of the event occlusion conditions for the expert and novice groups in Experiment 2.

Significant differences between the groups exist on all conditions except e1.
Figure 79: Increases in radial error in the prediction of the shuttle landing position attributable to specific cue occlusion for the expert and novice groups in Experiment 2. (Increases are expressed relative to the control condition e5).

Significant differences exist between the groups on conditions e1 and e2.
and the arm emerge as significant sources of anticipatory information (condition e1 having greater error than e2 with both these conditions inducing more error than the control condition e5). For the novice group only the racquet emerges as a significant anticipatory cue with the radial error induced by arm and racquet occlusion (e1) being the same as that under racquet occlusion conditions (e2) alone. These conclusions regarding cue usage are identical to those reached earlier with the larger sample (see Figure 32).

When the differences in anticipatory performance between the expert and novice groups under control conditions are accounted for by the computation of difference scores (Figure 79), it again becomes apparent (cf Figure 33) that expert players are characterized by a greater capacity for extracting information from both the racquet and the arm holding the racquet. The statistical conclusions reached in Experiment 1 regarding the differences in perceptual strategy between the expert and novice performers, are therefore again obtained for the subjects in this experiment.

Therefore, as the sample of expert and novice subjects selected in this experiment for concurrent scan pattern recording behave, both in terms of their temporal and spatial dependence on different cue sources, in a manner identical to that of the larger sample of expert and novice subjects used in Experiment 1, direct comparison of the visual search pattern characteristics derived from this experiment with the prediction performance characteristics established in Experiment 1 appears to be justified. More detailed examination of the visual search
Figure 80: Percentage of occasions in which each fixation location occupies the first position in the visual search sequence for the expert and novice groups in Experiment 2.
characteristics of this present sample are made in the sections that follow.

(2) Search Pattern Sequence Analysis

In an attempt to objectively evaluate the search pattern sequences used by the expert and novice performers the percentage of time each of the possible fixation locations precedes, or is itself preceded by, every other fixation location was determined. This approach was seen as potentially more valuable than the traditional scan path plots used with static stimuli (e.g. Noton & Stark, 1971) in that it allows a more quantifiable form of sequential index to be derived, as advocated by Megaw and Richardson (1979, p. 147). In each case the determination of the sequential dependencies in the fixation locations was made over the full display condition (t5) to provide all cue sources, including those such as shuttle flight cues available only late in the event sequence, an opportunity to be incorporated into the search sequence.

The analysis of the search sequence is commenced here by considering the proportion of the total trials in which each cue occupied the first position in the search series.

(i) Initial Fixation Location Occurrences

Figure 80 presents, for both experts and novices, the percentage of times in which each of the eight possible fixation locations is used as the first fixation in the visual search sequence. Clearly in most cases the initial recorded fixation (or the first fixation transcending the film trial period) is
Figure 81: Relative frequency of fixation locations immediately following screen centre fixations for all subjects in Experiment 2.

In a further 5% of cases one screen centre fixation was immediately followed by another whereas in 11% of cases the subsequent fixation location could not be determined.
Figure 8.2: Relative frequency of fixation locations immediately following screen centre fixations for expert and novice subjects in Experiment 2.
Figure 83: Relative frequency of fixation locations prior to, and subsequent to, fixations upon the opponent’s lower body for all subjects in Experiment 2.

In 23% of cases the preceding location is the screen centre. 4% of preceding locations and 6% of subsequent fixation locations were not determinable.
generally a screen centre fixation and this is undoubtably a legacy of
the subject's fixations on the screen centre in awaiting the appearance
of film information and a consequence then of the ocular latency in
responding to the film's appearance. A more enlightening analysis
therefore may be to consider the proportion of times the other possible
locations are fixated immediately following a screen centre fixation.

When the relative frequency of fixation locations immediately
following screen centre fixations are considered (Figure 81) it becomes
apparent that the racquet and the opponent's head, trunk and, to a
lesser extent, lower body are the most frequently used locations early in
the visual search sequence, therefore indicating a need to consider these
particular display areas independently. Although the same major areas of
the display attract early fixations for both skill groups there is a
trend (see Figure 82) towards experts making a higher proportion of early
fixations upon the racquet area and a lower proportion of early fixations
upon the opponent's head, trunk and feet, in contrast to the novice
performers.

In order to make further implications regarding the 'usual' search
order of the respective feet, trunk, head and racquet areas each of these
potential cues will now be considered in turn, with respect to their most
frequent preceding and following fixation locations.

(II) Fixation Locations Preceding and Following Lower Body
Fixations. In Figure 83 the most frequent fixation locations prior to,
and subsequent to, fixations upon the opponent's lower body are
considered. From this figure it can be observed that fixations on the
lower body follow either screen centre fixations, racquet fixations,
Figure 84: Relative frequency of fixation locations immediately preceding fixations on the opponent's lower body for the expert and novice groups in Experiment 2.

In 2.4% of cases for experts and 1.9% of cases for novices the lower body is the first fixation location in the search sequence.
Figure 85: Relative frequency of fixation locations immediately following fixations on the opponent's lower body for the expert and novice groups in Experiment 2.

In 4.8% of cases for the expert group the lower body is the last fixation in the search sequence.
Figure 86: Relative frequency of fixation locations prior to, and subsequent to, fixations upon the opponent's trunk for all subjects in Experiment 2.

In 80% of cases the trunk is fixated either first in the search sequence or immediately following a screen centre fixation. 1% of fixations preceding the trunk and 4% of fixations following the trunk were not determinable.
Figure 87: Relative frequency of fixation locations immediately preceding fixations on the opponent's trunk for the expert and novice groups in Experiment 2.

In 22.1% of cases for experts and 18.7% of cases for novices the trunk is the first fixation in the search sequence.
Figure 88: Relative frequency of fixation locations immediately following fixations on the opponent's trunk for the expert and novice groups in Experiment 2.
trunk fixations or other lower body fixations with approximately equal frequency. On the other hand, after a fixation has been made on the lower body, the most predominant subsequent fixation location is clearly the racquet, suggesting that, in the normal search sequence, lower body fixations usually occur prior to those on the racquet and once a shift in visual attention is made to the racquet, fixations return to the lower body relatively infrequently (see also Figure 92). The role of the fixations upon the lower body in the visual search sequence is a relatively stable one for both skill groups with no obvious differences in the scan sequence with respect to visual search of the lower body region (i.e. the legs and feet) being evident (see Figures 84 and 85).

(iii) Fixation Locations Preceding and Following Trunk Fixations
Fixations upon the opponent's trunk occur primarily early in the visual search sequence, being the first fixation on about 20% of occasions and following the preliminary screen centre fixations a further 58-59% of the time. As was the case with lower body fixations visual attention is usually shifted from the trunk immediately to the racquet (see Figure 86) although on a number of occasions fixations to either of the body extremes (i.e. either the head or the lower body) occur. Again minimal differences in the sequential characteristics of the expert and novice group's visual search are apparent at least with respect to these trunk cues (see Figures 87 and 88), indicating the persistence of some common visual search characteristics across the different proficiency groups.

(iv) Fixation Locations Preceding and Following Head Fixations
Like the case of the trunk fixations examined above ocular fixations upon the
Figure 89: Relative frequency of fixation locations prior to, and subsequent to, fixations upon the opponent's head for all subjects in Experiment 2.

In 73% of cases the head is fixated either first in the search sequence or immediately following a screen centre fixation. 2% of fixations preceding the head and 4% of fixations following the head were not determinable.
Figure 90: Relative frequency of fixation locations immediately preceding fixations on the opponent's head for the expert and novice groups in Experiment 2.

In 25.2% of cases for experts and 19.9% of cases for novices head fixations occupy the first position in the search sequence.
Figure 91: Relative frequency of fixation locations immediately following fixations on the opponent's head for the expert and novice groups in Experiment 2.
Figure 92: Relative frequency of fixation locations prior to, and subsequent to, fixations upon the racquet for all subjects in Experiment 2.

In some 15% of cases the racquet either follows a screen centre fixation or is the first fixation in the series whereas in some 26% of cases the racquet is the final fixation.
opponent's head occur with greatest prevalence early in the search sequence with fixations on the head and face region occupying the initial position in the scan sequence on some 28% of occasions and following the initial screen centre fixations on some 53% of occasions. As with the other fixation locations examined to date, the racquet area is the most frequently used fixation location following fixations upon the opponent's head (see Figure 89), although in some 12-13% of cases an additional fixation on the head is also made. Once the eye has moved from fixating upon the opponent's head to fixating upon the racquet and surrounding areas there is only a very low probability of foveal vision being returned to the head (see also Figure 92). No marked skill group differences are evident in the role of fixations upon the opponent's head in the composite visual search sequence, with the possible exception of the observation that experts are less likely than the novices to make a second (or series) of fixations upon the head (Figures 90 and 91). For the experts the visual focus appears to be moved more rapidly away from the opponent's head to the racquet arm than is the case for the novice performers.

(v) Fixation Locations Preceding and Following Racquet Fixations
As the racquet appears to be a terminal fixation location for many of the other cues already examined, analysis of racquet sequential information appears potentially very important in the derivation of a clearer description of the general scan pattern sequence. Analysis of the relative frequencies of fixation locations preceding and following racquet fixations (Figure 92) reveals that, although a wide range of fixation locations are seen to precede fixations on the racquet (viz the
Figure 93: Relative frequency of fixation locations immediately preceding fixations on the racquet for the expert and novice groups in Experiment 2.

Racquet fixations occupy the first position in the search sequence for 1.9% of cases for experts and 0.9% of cases for novices.
Figure 94: Relative frequency of fixation locations immediately following fixations on the racquet for the expert and novice groups in Experiment 2.

Racquet fixations occupy the final position in the search sequence for 29.9% of cases for experts and 22.5% of cases for novices.
Figure 95: Relative frequency of fixation locations prior to, and subsequent to, fixations upon shuttle outflight for all subjects in Experiment 2.

In 84% of cases the shuttle is the last area fixated in the search sequence.
Figure 96: Relative frequency of fixation locations immediately preceding fixations on shuttle outflight for the expert and novice groups in Experiment 2.
Figure 97: Relative frequency of fixation locations immediately following fixations on shuttle outflight for the expert and novice groups in Experiment 2.

Shuttle fixations occupy the final position in the search sequence for 87.0% of cases for experts and 80.9% of cases for novices.
screen centre, the opponent's head, trunk and lower body), once visual focus is shifted to the racquet it either remains there (as it does in some 80% of cases) or moves to observation of the shuttle in its outflight stages. This implicates the racquet as the item of the highest priority in the subject's visual search pattern and implicates an essentially dominant role for this cue source late in the search sequence. Minimal differences in the use of the racquet as a visual cue are evident between the skill groups, both in the analysis of the preceding (Figure 93) and the following (Figure 94) fixation locations, again suggesting a relative generality in the sequential nature of the visual search adopted by all subjects.

(vi) **Fixation Locations: Preceding and Following Shuttle Fixations** As was noted above, fixations upon the shuttle in flight are preceded, almost universally, by racquet fixations (Figure 95). Once the shuttle has been fixated, the most probable subsequent fixation is a further sample of shuttle outflight, although in the majority of instances, the shuttle is the last cue fixated prior to film trial cessation. Again this effect regarding the position of shuttle fixation within the scan sequence holds across the different skill groups (Figures 96 and 97).

(vii) **Final Fixation Location Occurrences** Figure 98 presents the average percentage of trials on which each particular fixation location occupies the final position in the scan sequence (i.e. the final fixation on the film screen prior to shifting the visual focus down to the response sheet). Quite clearly not all locations are equiprobable in terms of being the locus for the final fixation in the visual search
Figure 98: Relative frequency of fixation locations immediately preceding the final fixation in the visual search sequence for all subjects in Experiment 2.

In 18% of cases, fixations on the screen centre after film occlusion are the last fixations in the search sequence.
Figure 99: Percentage of occasions in which each fixation location occupies the final position in the visual search sequence for the expert and novice groups in Experiment 2.
sequence. The racquet has the highest probability, followed by the shuttle, indicating that although shuttle flight information is always available it is sampled foveally on a relatively limited number of occasions. In some 18% of cases in which full display information is available further fixations occur on the screen after the film trial's cessation (designated by code y) and this possibly reflects the subject's uncertainty about the information presented or perhaps reflects an attempt by the subjects to utilize any available iconic persistence of the visual stimulus to further enhance response selection. (These effects will be considered in a subsequent analysis where the dwell time parameter is considered as a possible indicator of perceived task difficulty).

Some possible proficiency-related differences in final fixation location are also evident (see Figure 99). Experts appear to have the racquet as the final fixation in their search sequence more often than the novices who, in contrast, appear to place greater reliance on the shuttle and additional on-screen fixations after the film occlusion as the ultimate fixation in the search sequence. These differences perhaps reflect the redundant nature of much of the shuttle outflight for experts and the consequent lack of necessity, at least foveally, to sample information from the shuttle in flight in order to generate predictions about the shuttle's landing position.

Conclusions Regarding the Search Pattern Sequence

The sequential analyses, along with the subjective observations of the
search patterns, suggests that the following general search sequence is adopted by most subjects.

(1) Firstly the subjects prepare themselves for the film trial onset by fixating in proximity to the screen centre; that being the general area of the display in which there is the highest probability of the opponent being located when the film trial information appears.

(2) Once the film display appears there is some inevitable latency before the first saccadic eye movement is made (this will be considered later when the VCT parameter is analyzed), with the most probable subsequent fixation target being generally the gross areas of the body, especially the trunk, head or lower body. It would appear that these initial fixations are primarily concerned with the orientation of visual focus to the general body position and configuration of the opponent (e.g. determination of the direction in which the player is moving) and extraction of early information regarding initial stroke development (e.g. determination of whether it is a backhand or forehand posture).

(3) Once stroke execution commences the obvious high priority becomes spending as much time as possible with the racquet (and the arm?) as the point of regard, with this area of the display clearly providing the cues to which the subjects assign greatest pertinence. The racquet is, in most cases, the source of a number of successive fixations (see Figure 92) with the point of foveal vision intermittently altered to maintain a match with the racquet (and arm's) motion. In a substantial number of cases these racquet fixations occur without prior fixations on the opponent's body (i.e. stage 2).
(4) Once the shuttle has been struck visual focus is often shifted to the monitoring of the shuttle flight, through a series of short duration fixations and saccades although the full duration of shuttle flight is very rarely sampled. In many instances, however, the cues arising from the shuttle are not examined foveally indicating either the redundancy of the information provided by the shuttle or the possible use of peripheral vision in flight information extraction. The latter possibility seems unlikely however, in view of the observation that, in many cases, the cessation of either racquet or shuttle fixations is followed by an immediate saccadic movement of the eyes away from the viewing screen and a subsequent initiation of head movements to draw the visual field down to the response sheet. In the cases where saccadic eye movements accompanied shuttle flight the onset of the first saccade to the shuttle generally lagged behind shuttle flight onset although there were a few isolated occurrences of anticipatory saccades in the predicted direction of shuttle outflight being elicited in trials (most obviously the +3 occlusion condition) where actual shuttle flight information was not provided.

Each of these stages in the general search pattern sequence is enlightening in terms of understanding the visual search strategies adopted by performers in racquet sports such as badminton. Specifically the initial strategy of waiting in screen centre for the film (stimulus) onset appears to reflect, as one would expect from selective attention theory, the subjects a priori expectations regarding the spatial probability of information occurrence. This concurs with the evidence previously gathered from visual search analyses of static tasks (e.g.
Kundel & La Follette, 1972; Mackworth & Morandi, 1967) which demonstrates the powerful deterministic role of expectancy upon the initial fixation locations.

Furthermore, the bulk of the visual search sequence reflects a close match between the changes in the point of visual orientation and the changes in the kinetic and kinematic properties of the stroke production action. In keeping with the force generation and transfer changes from proximal to distal segments of the body in the production of the forehand and backhand motions (Plagelhoef, 1971) there appears to be a corresponding evolution of the visual search sequence from an initial proximal orientation (i.e. fixations on the lower body, head and especially the trunk of the opponent) to a later dominant distal orientation (i.e. fixations upon the racquet and supporting limb extremities). This close matching of visual search parameter changes with environmental changes is supportive of the matching effects reported previously with static problem-solving tasks (Just & Carpenter, 1976) and implicates a close logical link between the recorded search patterns in this dynamic task and the potential information content of the display. Some of the existing German studies of visual search in sport (especially Neumaier's 1982 data from the eye movement recording of gymnastics observers) also appear to show this close approximation of the visual search patterns to the emerging biomechanical characteristics of the action being viewed.

Although many of the successive changes in fixation location involve displacement of the fovea to new positions within close spatial proximity
to the previous location, in keeping with the observations of Bard et. al. (1981) in their study of fencers, this does not appear here to be the critical driving factor behind subsequent fixation location selection. Rather the selection of the next fixation location appears to be primarily a function of the relative time of cue occurrences within the event sequence (e.g. selection of a trunk fixation is more likely to occur early in the search sequence than late) and the apparent necessity to locate and fixate upon the high priority racquet cues for as long a period as possible.

Similarly even though some consistent individual differences in search sequences are evident (e.g. 3 of the novice subjects and 2 of the expert subjects utilized a strategy which involved the persistent switching of visual attention between the feet and the racquet, up until the point of racquet-shuttle contact), the occurrence of a systematic proximal-to-distal search sequence appears reasonably consistent across both the expert and novice skill group samples. It would therefore appear that the time constraints imposed by dynamic display tasks may act to constrain somewhat the search orders which are possible within these kinds of tasks. Specifically dynamic display tasks such as in this experiment and the rifle shooting analyses reported by Ripoll et. al. (1983) appear to encourage far more predictable fixation orders by the subjects than are evident in static, non-time-constrained tasks such as picture viewing (e.g. Yarbus, 1967).

Direct comparison of the current observations on search sequence with the strategies reported in the only other visual search analysis of
racquet sports (Ritzdorf's 1983 eye movement recording studies of tennis players) is difficult because of the inaccessibility of the original material. 33 Nevertheless it appears that only one of three observational strategies reported by Ritzdorf (i.e. fixations in the order shoulder-shoulder-ball) are actively used by badminton players in this task situation. In no instances in the current experiment, for either experts or novices, were fixations in the order of shoulder-ball-shoulder observed nor were continuing eye movements following the shuttle, although this latter strategy was partially prevented in this experiment through the lack of visibility provided for the inward flight of the shuttle. The observation of the eye movements utilized in visually analyzing the shuttle outflight however, provides useful information regarding the means by which object flight parameters are extracted.

As has been noted previously, when all shuttle flight information is available to the subjects in this experiment (i.e. in the condition t5), this information is seldom monitored exhaustively and in many cases focal vision remains on the racquet rather than shifting to the shuttle. Movements of the head away from the display in this experiment and toward the response sheet were frequently observed to occur prior to the cessation of shuttle flight information or the onset of film occlusion. This observation of broken monitoring of shuttle outflight suggests that

33. The original research is written in German and only English summaries are readily available.
the majority of information conveyed by the shuttle late in its flight is redundant, acting only to confirm perceptual judgments made from information extracted much earlier in the stroke sequence. This concept of late shuttle flight redundancy is supported by the persistent observation of asymptotes in prediction accuracies from temporal occlusion conditions t4 - t5 in Experiment 1 (see Figures 24 or 77) and is consistent with the observation that in 'real world' settings the ocular tracking of ball flight is generally incomplete, being broken some distance before racquet or bat contact (Hubbard & Seng, 1954; Stein & Slatt, 1981). This observation of discontinued visual focus upon the shuttle in flight adds further support to Whiting's (1969) contentions regarding the fallacious nature of the generalization of 'watching the ball right onto the bat or racquet' in fast ball sports.

In the instances where shuttle flight is monitored in the early stages of flight it is done through the use of saccadic rather than smooth pursuit (or tracking) eye movements. In Gregory's (1966) terms this indicates a reliance upon the image-retina system (i.e. the system where the retina is stable and the image passes over the retina) rather than the eye-head system (i.e. the system where the head is stable and the eyes track the moving object to maintain constant foveation) for the extraction of object velocity information. Although smooth pursuit eye movements provide a more accurate velocity estimate than saccadic movements at low target velocities (Cohen, 1962), the use of saccadic eye movements in this particular experimental setting is to be expected because the usefulness of the smooth pursuit system seems limited when the absolute target velocity increases (Williams & Fender, 1979) or the
angular velocity exceeds some 30°/second (Haywood, 1977; Noorden & Mackenson, 1962; Westheimer, 1954). Furthermore as previous studies have also indicated that the image-retina system rather than the eye-head system is more likely to be utilized (Sharp and Whiting, 1975) when the time available to view object motion is restricted to below approximately 240 msec, the use of saccadic eye movements, particularly as they are already in use for extracting information from pre-flight cues, is not surprising. This observation of exclusive use of the saccadic eye movement system for information extraction throughout the full duration of the film trials does, however, obviously bring under substantial question studies which attempt to differentiate performance levels on the basis of ocular tracking tasks (e.g. Mott, 1954; Trachtman, 1973) and approaches to skill improvement which are based upon the enhancement of the capability of the eye-head system (e.g. Revien & Gabor, 1981).

Overall therefore, consideration of the sequence information in the visual search patterns is considerably enlightening, particularly in terms of understanding the general means by which the subjects search the display in order to extract task-relevant information. Most particularly, the observation regarding the great predominance of racquet fixations and the priority accorded to the racquet at all stages in the search sequence, carries with it substantial implications regarding the criticality of this cue source in terms of its potential information content and the need to examine the overall usage of the different cue sources more objectively.

In the section that follows the relative visual usage of the different
Figure 100: Percentage of trial time allocated to each fixation location for the expert and novice groups in Experiment 2.

Significant differences exist between groups for head, trunk and shuttle fixations.
sections of the display is examined in greater detail with a view towards discerning possible proficiency-related differences in the reliance upon different cue sources.

(3) Fixation Location Analyses

(a) Proficiency Level Effects

Figure 100 presents the average percentage of time on each trial which is spent with the eye fixated on each of the major sections of the film display. When the mean percentage of trial time allocated to each cue is considered it becomes apparent, as suggested by the earlier sequential analyses, that both expert and novice subjects allocate attentional priority to the racquet region as the dominant source of task-relevant information. Fixations upon other regions of the display appear to be clearly of sub-ordinate importance for both skill groups.

Significant differences are evident between the skill groups in terms of greater allocation of available trial time by the novices to fixations upon the head ($F(1,29)=5.656, p<.05$), trunk ($F(1,29)=6.703, p<.05$) and shuttle ($F(1,29)=8.628, p<.05$) but these differences, because of the small absolute time allocated to these cue sources by both skill groups, are of little practical consequence. Within the limits of the spatial isolation of display regions set by the eye movement recording procedure therefore, the allocation of foveal attention appears, to all intents and purposes, to be essentially similar between the two skill groups, with both groups according the racquet region maximum priority. This observation of skill group similarities in the allocation of visual selective attention is
Figure 101: Percentage of total number of fixations allocated to each fixation location for the expert and novice groups in Experiment 2.

Figures are based on t5 trials only i.e., trials in which information from all sections of the display is available to the subjects.
obviously contrary to a number of earlier visual search analyses of both
sport and ergonomics, in which differences in the number of fixations
experts and novices allocate to the available visual cues have been
reported (cf Table 4).

The majority of the earlier studies available examining proficiency-
related differences in visual search have proceeded by determining the
percentage of total fixations given to each display feature rather than
by considering the percentage of trial time which is normally allocated
to each cue (as in Figure 100). Although this form of analysis seems
less appropriate than the one currently used (fixations of different
duration being implied to be equally important in these existing
approaches) the percentage of total fixations given to each cue source is
nevertheless presented in Figure 101 to facilitate more direct comparison
with the earlier studies.

Even when the dependent measure of cue usage is altered to bring it in
line with earlier studies no obvious differences in cue usage emerge
between the expert and novice skill groups. Therefore, regardless of the
dependent measure used, this study seems at variance to the limited
existing sport-specific visual search literature (e.g. Bard & Fleury,
1976a; Bard et. al., 1980, 1983; Ripoll et. al. 1981) in terms of
observing similarities rather than differences in the priority accorded
to different features of the perceptual display by the two skill groups.
Although, as with the relative time measure in Figure 100, significant
differences are achieved statistically between the skill groups in the
relative use of some of the minor cue sources (viz the head and the
trunk) these differences are of little substantive importance and cannot be expected to account for all the prediction performance variance which has been observed previously (Figure 77). As this current study in finding no skill group differences uses a far greater sample size than any of the other earlier sport-specific visual search studies (see Table 4) and as the existing studies indicating proficiency-related differences originate from essentially the one research laboratory only,\(^{34}\) considerable doubt must now be cast upon the importance of the overt visual search pattern as a determinant of perceptual performance differences in sport.

The current study does however, share a number of commonalities with existing visual search studies of sport especially with respect to the importance assigned to different display cues for efficient task performance. For example, it appears that in this sport, badminton, as in other sports where the opponents face each other directly (e.g. see Bard et. al.'s 1981 work on fencing), the opponent's head and face are rarely fixated and this is probably because these areas usually provide deceptive or irrelevant cues rather than reliable information. As Ekman and Friesen (1969) have noted, the face appears to be the major non-verbal liar and subjects of both skill levels seem aware of this, making very few fixations on this area of the display under any of the task conditions. Similarly the lower body does not appear to be a particularly frequently utilized source of visual information for

\(^{34}\) Findings replicated by only the the same research centre are frequently regarded within review articles as low-level facts (e.g. see Andrews et. al., 1983)
performers in sports skills where the predominant action involves the use of the hands or some extension of the hands. In this study, as in the visual search analyses of fencing (Bard et al., 1980), ice-hockey goal tending (Bard & Fleury, 1981) and volleyball reception (Neumaier, 1983), the lower body is rarely fixated. The principal cues in these striking sports have previously been seen to usually arise from the implement held in the hand (e.g. the stick in ice-hockey; Bard & Fleury, 1981) or from the hand and arm itself (e.g. as in Bard et al.'s 1981 fencing study), and this also appears to be the case in this study where disproportionately high numbers of fixations are made upon the racquet (and possibly also the supporting arm).

Methodologically the most important single concern within the visual search analysis is to determine the extent to which the cue priorities implied from the fixation location frequencies match the cue priorities for information extraction, as determined from the earlier event occlusion analysis. Although the assumptions of visual foveation reflecting cue priority and of visual orientation matching attentional focus are fundamental to the validity of the use of the eye movement recording approach in dynamic situations such as sport (see again Chapter 4, pp. 165), these assumptions have never been previously examined in applied studies. For this reason the comparison of the results of the event occlusion analyses with the relative frequencies of fixation location usage is a very critical one in the assessment of the validity of the ever-increasing use of eye movement recording in sport. Figure 102 presents, from the event occlusion analyses, the respective contributions to prediction performance which are attributable to information available
Figure 102: Respective importance of different display cues for the expert and novice groups in Experiment 2 as determined from (a) the event occlusion analysis and (b) the visual search analysis.
from the racquet and arm (e1), the player's head (e3) and the player's lower body (e4) and compares this to the percentage time which is normally spent on each trial in fixating upon these different areas.

A number of conclusions can be drawn from the comparison of these two methods of imly cue usage. Firstly both analyses lead to the same general conclusions regarding the respective importance of cues from these three global regions of the display in prediction of the forthcoming landing position of the shuttle. Specifically both methods lead to the conclusion that the racquet (and possibly also the arm) is the most critical source of advance information and that the opponent's head, trunk and lower body position are relatively unimportant - conclusions which are also compatible with the performer's own estimates of their cue usage. These findings therefore indicate a relatively close concurrence between the subject's visual orientation and their attentional orientation for this particular dynamic task. The problem of attentional shifts around the same fixation location identified in Chapter 4 may then be seen to be confined primarily to static, non-time-constrained displays and tasks. However, an alternate argument may be advanced that the use of a confined filmed display for this study does not encourage subjects to shift their attention into the peripheral field, without eye movements, to the same extent as do completely 'real world' tasks.

Secondly the major discrepancy evident between the two approaches to cue usage determination is the inability of the visual search analysis to discriminate skill group differences in cue usage, specifically the
expert group's greater ability to utilize information provided by arm cues. As skill group differences in stroke prediction ability are evident when only advance sources of information are available (Figure 77) some cause for the observed skill group differences needs to be found within the data presented in Figure 102, but this is only forthcoming for the event occlusion analysis. It would appear then that the discrepancy in the skill group differences observed between the two methods may be due to either (a) the possibility that experts do indeed make a greater number of fixations on the player's arm than do the novices (as concluded from the event occlusion analyses) but that these racquet and arm fixation locations can not be differentiated because of the precision limitations inherent in the eye movement recording apparatus or (b) the more probable possibility that, although both skill groups display similar search patterns, the experts possess a greater ability than the novices to extract more useful information from the same fixation locations. This latter possibility suggests that, although both experts and novices fixate with equal frequency upon the racquet (and the supporting arm), only the experts have the necessary prior knowledge, and perhaps cognitive structures, to extract usable information from the arm. As only the event occlusion procedure is based upon actual information extraction (rather than merely visual orientation) this method would appear to be a superior one for the examination of actual cue usage differences between expert and novice performers.35

In Figure 102(b) the mean percentage of trial time allocated to each area of the display was examined for one specific film occlusion
Figure 103: Mean percentage of trial time allocated to each fixation location (cue source) for occlusion conditions (a) t1 and (b) t5 for the expert and novice groups in Experiment 2.
TABLE 8

Mean percentages of trial time allocated to each fixation location (cue source) for each of the temporal occlusion conditions for the expert and novice groups used in Experiment 2

<table>
<thead>
<tr>
<th>Fixation Location</th>
<th>Temporal Occlusion Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t1</td>
</tr>
<tr>
<td><strong>Racquet Experts</strong></td>
<td>67.48</td>
</tr>
<tr>
<td><strong>Novices</strong></td>
<td>60.87</td>
</tr>
<tr>
<td><strong>Shuttle Outflight Experts</strong></td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Novices</strong></td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Trunk Experts</strong></td>
<td>5.36</td>
</tr>
<tr>
<td><strong>Novices</strong></td>
<td>8.20</td>
</tr>
<tr>
<td><strong>Head Experts</strong></td>
<td>6.64</td>
</tr>
<tr>
<td><strong>Novices</strong></td>
<td>11.91</td>
</tr>
<tr>
<td><strong>Feet Experts</strong></td>
<td>1.29</td>
</tr>
<tr>
<td><strong>Novices</strong></td>
<td>3.94</td>
</tr>
<tr>
<td><strong>Screen Centre Experts</strong></td>
<td>12.61</td>
</tr>
<tr>
<td><strong>Novices</strong></td>
<td>11.39</td>
</tr>
<tr>
<td><strong>Not Determinable Experts</strong></td>
<td>6.78</td>
</tr>
<tr>
<td><strong>Novices</strong></td>
<td>4.08</td>
</tr>
</tbody>
</table>

<sup>a</sup> Anticipatory saccade for shuttle outflight.
condition (i.e., e5) rather than across all of the occlusion conditions as it had been in the earlier analyses (Figure 100). As examination of the changes in fixation location frequency across each of the different film occlusion conditions is potentially useful in terms of both reinforcing existing conclusions regarding the search pattern sequence and validating some of the assumptions underlying the use of the occlusion procedures, these task condition effects will now be examined.

(b) Task Condition Effects

Temporal Occlusion Conditions

Table 8 lists the mean percentage of each trial which is allocated to fixations in each area of the display for each of the five temporal occlusion conditions. The fixation locations for the extreme conditions t1 and t5 are also plotted for comparative purposes in Figure 103. Both these forms of data presentation show clearly that with increased availability of temporal information (in the transition from condition t1 through to condition t5) there is a progressive increase in the percentage of each trial which is allocated to the racquet and shuttle and a progressive decrease in the allocation of viewing time to other cue sources. In keeping with the conclusions reached earlier regarding the search sequence utilized by both skill groups this data also clearly supports the conclusions that there is (a) a greater reliance on trunk, 

35. The use of the eye movement recording approach in tandem with the event occlusion analysis would still however appear to be the most desirable approach, as the multiple level of analysis reduces the probability of erroneous conclusions from either individual method. In the sections which follow the eye movement recording analysis will conversely be utilized to examine some of the assumptions underlying the validity of the event occlusion procedure.
TABLE 9

Mean percentages of trial time allocated to each fixation location (cue source) for each of the event occlusion conditions for the expert and novice groups used in Experiment 2

<table>
<thead>
<tr>
<th>Fixation Location</th>
<th>Event Occlusion Conditions</th>
<th>e1</th>
<th>e2</th>
<th>e3</th>
<th>e4</th>
<th>e5</th>
<th>t3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Racquet (%r)</td>
<td>Experts</td>
<td>65.46</td>
<td>66.13</td>
<td>66.13</td>
<td>66.41</td>
<td>68.52</td>
<td>68.74</td>
</tr>
<tr>
<td></td>
<td>Novices</td>
<td>63.24</td>
<td>64.26</td>
<td>66.35</td>
<td>65.23</td>
<td>65.41</td>
<td>64.85</td>
</tr>
<tr>
<td>Shuttle Outflight (%s)</td>
<td>Experts</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>Novices</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Trunk (%t)</td>
<td>Experts</td>
<td>4.81</td>
<td>3.79</td>
<td>4.77</td>
<td>3.24</td>
<td>3.34</td>
<td>4.87</td>
</tr>
<tr>
<td></td>
<td>Novices</td>
<td>6.38</td>
<td>6.58</td>
<td>5.55</td>
<td>6.14</td>
<td>6.40</td>
<td>7.68</td>
</tr>
<tr>
<td>Head (%h)</td>
<td>Experts</td>
<td>5.06</td>
<td>5.26</td>
<td>4.20</td>
<td>7.66</td>
<td>4.86</td>
<td>6.45</td>
</tr>
<tr>
<td></td>
<td>Novices</td>
<td>10.18</td>
<td>10.28</td>
<td>9.22</td>
<td>9.68</td>
<td>8.09</td>
<td>10.95</td>
</tr>
<tr>
<td>Feet (%f)</td>
<td>Experts</td>
<td>1.39</td>
<td>1.29</td>
<td>0.55</td>
<td>0.89</td>
<td>1.07</td>
<td>2.39</td>
</tr>
<tr>
<td></td>
<td>Novices</td>
<td>0.98</td>
<td>0.60</td>
<td>1.09</td>
<td>0.45</td>
<td>0.99</td>
<td>3.00</td>
</tr>
<tr>
<td>Screen Centre (%x)</td>
<td>Experts</td>
<td>19.00</td>
<td>17.53</td>
<td>18.11</td>
<td>17.57</td>
<td>17.42</td>
<td>11.60</td>
</tr>
<tr>
<td></td>
<td>Novices</td>
<td>17.42</td>
<td>15.62</td>
<td>15.57</td>
<td>18.04</td>
<td>16.37</td>
<td>9.50</td>
</tr>
<tr>
<td>Not Determinable (%n)</td>
<td>Experts</td>
<td>4.61</td>
<td>6.24</td>
<td>6.94</td>
<td>5.69</td>
<td>6.06</td>
<td>5.89</td>
</tr>
<tr>
<td></td>
<td>Novices</td>
<td>1.80</td>
<td>2.80</td>
<td>2.48</td>
<td>2.50</td>
<td>2.73</td>
<td>4.02</td>
</tr>
</tbody>
</table>
head, lower body and screen centre fixations early rather than late in the stroke sequence, although even as early as 168 msec prior to contact (i.e. t1) racquet fixations are predominant and that (b) there is an almost singular reliance on cues from the racquet and shuttle later in the stroke sequence.

The proximal-to-distal notion of search progression is also therefore indirectly supported by this time-series type of analysis.

Event Occlusion Effects

Comparative examination of the percentage of trial time allocated to fixations in each of the display areas for the five event occlusion trials, plus the temporal occlusion control condition (t3), is provided in Table 9.

Although some very minor reductions in the frequency of searching different cues are evident when specific cues are occluded (e.g. when the racquet and arm are occluded in e1 the mean percentage of trial time given to racquet region fixations decreases to 64% from the 67% obtained under the control condition e5) the most striking feature of this data is how little effect specific cue occlusion has upon the search pattern. For example, in the above-cited case where the racquet and arm are occluded the eye still fixates upon those regions (or where the cues should be) for some 64% of the viewing time even though no information is now available from these areas!

The data indicates clearly therefore that very little change in the
Figure 104: Mean percentage of trial time allocated to each fixation location for (a) down-line and (b) cross-court strokes for the expert and novice groups used in Experiment 2.

Comparison is made on the occlusion condition t4.
Figure 105: Mean percentage of trial time allocated to each fixation location for (a) smash and (b) drop-shots for the expert and novice groups used in Experiment 2.

Comparison is made at the occlusion condition t4.
search pattern occurs as a consequence of specific cue occlusion, supporting in principle the capability of the event occlusion paradigm to make controlled comparison of cue usage without inducing the subjects to elicit non-normal or 'adaptive' search patterns. Subjects from both skill groups show remarkably little adaptability to cope with the altered task demands brought about by each specific event occlusion condition. Changes in search pattern characteristics during the course of a trial are apparently difficult to make because the trial times are sufficiently short that insufficient time exists to substantially modify the search pattern and the presentation of the event occlusion conditions in random order prevents any search modifications from being prepared before the trial. The rigid nature of the search patterns elicited suggests that the search sequence may be controlled by some overriding perceptual framework (perhaps like the 'feature-ring' for recognition proposed by Noton & Stark, 1971), which acts to pre-set and constrain the order and location of the fixations within the search pattern.

**Stroke Type Effects**

Figures 104 and 105 present the comparative fixation location distributions for cross-court and down-the-line strokes (Figure 104) and smashes and drop-shots (Figure 105) as examples of the effect of stroke type differences upon cue usage. Again, despite some minor variation in location frequencies, the most dominant feature is the similarity of the search pattern (in terms of percentage time allocation per cue) across all stroke types and across different proficiency levels. All subjects, irrespective of their badminton playing expertise, appear to place
similar reliance on the different locations for information within the
display and this preferential use of the available cues does not appear
to alter substantially across the stroke types. In view of the earlier
observed differences in both prediction ease and cue usage for the
different stroke types there again appears to be evidence of
discrepancies between visual orientation to cues (as assessed from the
scan pattern analysis) and active usage of these cues for the purpose of
information extraction (as assessed from the event occlusion analyses).
Once again the need for caution in attempting to imply cue usage from
only fixation location frequency or density appears to emerge as a
dominant consideration.

(c) Conclusions Regarding Fixation Location Selection Within the Search
Pattern

The racquet area emerges as the dominant fixation location, being
fixated, on average, for some 60% of each trial, implicating this region
(including possibly also the arm) as the single most important source of
advance information for stroke prediction. This is as predicted from the
earlier event occlusion analysis (Figure 79) and as intimated from the
earlier analyses of the fixation sequence. However, in contrast to the
event occlusion analyses, no differences in fixation location frequencies
are evident between the skill groups or within the same skill groups for
different stroke types. This observation, along with the evidence
showing no alteration in cue usage for the different event occlusion
conditions (Table 9), demonstrates the use, by all subjects, of a
relatively consistent, apparently pre-established, pattern of fixation
locations.
In view of the differences in cue usage evident between the different skill groups and across the different stroke types from the event occlusion analyses, it becomes apparent that discrepancies exist with respect to the implication of cue importance from the fixation analyses and the event occlusion analyses. Validity checks performed suggest that greater reliance should be placed upon the results of the event occlusion analysis rather than the eye movement recording analysis. It appears that although subjects from the different skill groups visually orientate themselves to similar cues, the expert performers vary from the novices not in their search pattern characteristics, but rather in their ability to extract information from different fixation locations. Consequently in relation to the second research hypothesis proposed at the start of this chapter it appears that experts do indeed use different cues from those used by the novices, especially in terms of their greater utilization of arm information, although this is not evidenced, contrary to the conclusions reached in some earlier sport-specific studies, by any visual search differences.

The visual search analyses performed to date on the sequential and locational characteristics of the subject's fixations have allowed the second research hypothesis to be examined in some detail. In order to test the third hypothesis regarding differences in search rates between the experts and novices, assessment of the mean number of fixations per trial and of the mean fixation durations is necessary.
Mean number of fixations per trial for the temporal and event occlusion conditions for the expert and novice groups used in Experiment 2.

Figure 106: Mean number of fixations per trial for the temporal and event occlusion conditions for the expert and novice groups used in Experiment 2.

No significant differences exist between the groups on either set of conditions.
Figure 107: Mean number of fixations per trial as a function of the degree of temporal occlusion for the expert and novice groups used in Experiment 2.

No significant differences exist between the groups although, for both groups, significant differences exist between each adjacent occlusion condition.
(4) **Fixation Duration Analysis**

**Analysis of Mean Number of Fixations Per Trial**

In keeping with many of the other sport studies on visual search (especially Bard & Fleury, 1976a) initial comparisons of visual search rate were made by calculating the average number of fixations used per trial and using this measure to compare the respective search rates of the expert and novice performers. When the two skill groups are compared in this way (see Figure 106) no significant differences in the mean number of fixations used per trial are apparent either when the groups are compared on the temporal occlusions trials ($F(1,29)=3.123, p>.05$) or on the event occlusion trials ($F(1,29)=0.704, p>.05$). The apparent reduction in the number of fixations used per trial for the event occlusion conditions relative to the temporal occlusion conditions probably merely reflects the shorter overall trial durations in the event occlusion conditions rather than any systematic reduction in the visual search rate used.

Similar effects are observed when the mean number of fixations used per trial is compared between the five different temporal occlusion conditions (Figure 107). With each increment in temporal occlusion from $t_1$ through to $t_5$ there is an increase in the number of fixations required per trial ($F(4,116)=91.318, p<.05$) but this is again probably merely a reflection of the increased overall trial duration. No significant differences in the number of fixations used on each trial are apparent between the expert and novice group under any of the temporal occlusion conditions ($F(4,116)=2.359, p>.05$) despite the slightly higher average fixation rates evident for the novices under all five conditions.
Figure 108: Mean number of fixations per trial as a function of the event occlusion conditions for the expert and novice groups used in Experiment 2.

No significant differences exist between groups on any of the occlusion conditions.
Likewise when the event occlusion conditions are considered (Figure 108) both skill groups search at a statistically similar rate under all task conditions ($F(4,116)=2.104, p>.05$) although for both groups a greater number of fixations are required for trials in which the racquet only is occluded (e2) than in trials with head (e3), lower body (e4) or irrelevant (e5) occlusions ($F(4,116)=5.970, p<.05$). Overall therefore, in spite of consistently lower numbers of fixations per trial for the expert group for all 10 occlusion conditions these differences do not reach significant levels, thereby implicating the use of essentially comparable visual search rates for both expert and novice performers.

Although the parameter of the mean number of fixations per trial has been used in other sport-specific visual studies, it is often used more in the context of describing the number of fixations (or samples) required by the subject in order to reach some time-constrained response selection than in comparing search rates over a constant viewing period. For this reason, and the reasons outlined in Chapter 3 (see especially Figure 14), the use of mean fixation duration (FD) rather than the number of fixations/trial appears to be a more appropriate measure of search rate, especially given that FD also appears to bear a closer relationship to concurrent environmental changes than any of the other search parameters (Just & Carpenter, 1976). Consideration of FD allows the effect of the differences in total trial duration, which act on the number of fixation parameters, to be partialled out.

**Analysis of Mean Fixation Duration**

Figure 109 presents FD as a function of the temporal and event
Figure 109: Mean fixation duration for the temporal and event occlusion conditions for the expert and novice groups used in Experiment 2.

No significant differences exist either between groups or between occlusion conditions.
occlusion conditions for both the expert and novice groups. Because the same trial durations are viewed by all subjects in this experiment, unlike many of the prior sport-specific visual search studies, group differences in FD will merely reflect the inverse of the number of fixations parameter examined previously (refer again to Figure 14). Consequently, as was the case in the earlier proficiency analysis (Figure 106), no significant differences in the search rates for the expert and novice performers emerge ($F(1, 29) = 0.926, p > .05$) despite trends in the expected direction i.e. trends in the direction of longer FD, and hence slower sampling rates, for the experts.

Increased FDs are often reported in applied tasks as an indicator of performer fatigue (e.g. Stern & Bynum, 1979). As the temporal occlusion trials always precede the event occlusion trials any fatigue effects upon search rate in this experiment should then show themselves in the form of greater FDs under the event rather than temporal occlusion conditions. However, when the differences in overall trial duration are accounted for by use of the FD parameter, no significant differences in the search rates used for the temporal occlusion and event occlusion trials are apparent for either skill group ($F(1, 29) = 3.623, p > .05$) indicating an absence of visual fatigue effects.

When FD is plotted as a function of the independent temporal occlusion conditions (Figure 110) no skill group differences in search rate emerge ($F(1, 29) = 0.686, p > .05$) but there are some differences in FD apparent between the different temporal occlusion conditions ($F(4, 116) = 33.247, p < .05$). Specifically as the length of display
Figure 110: Mean fixation duration as a function of the degree of temporal occlusion for the expert and novice groups used in Experiment 2.

No significant differences exist between the groups on any of the occlusion conditions. For both groups significant reductions in FD occur from t1-t2, t2-t3 and from t4-t5.
No significant differences exist between the groups on any of the occlusion conditions.
information available to the subjects increases there are systematic reductions in FD with only the temporal increment from t3 to t4 failing to bring about a significant decrease in FD, and this effect is a little difficult to explain. The decrease in FD observed for later occlusion conditions, especially t5, may arise as a consequence, in part at least, of the increased number of short duration fixations which are made on the shuttle during the latter part of the event sequence. This cannot, however, account for the significant decrease in FD from condition t1 to t2, for example, nor for the overall trend for longer FDs on the more difficult task conditions. A feasible alternative explanation may be that the initial visual search for critical information requires relatively long FDs because of the need for additional time at each fixation location for information extraction. When more information becomes available (as with the later occlusion conditions t4 and t5) the search task then becomes more a process of confirming the existing information rather than extracting new information, and this confirmation process can apparently be accomplished through the use of shorter FDs.

For the event occlusion conditions (Figure 111) no group differences in FD are again evident ($F(1, 29)=1.022, p>0.05$) but some differences in FD exist between specific event occlusion conditions ($F(4, 116)=4.408, p<0.05$). Significantly shorter FDs are observed for the condition in which the player's lower body is occluded (e1) or the opponent's head is occluded (e3), but this effect seems of little practical consequence. Overall temporal rather than event occlusion manipulations of task difficulty appear to exert the most powerful influence upon FD.
Conclusions Regarding Search Rate Differences Within the Search Pattern

Both measures of search rate used (number of fixations per trial and $\overline{FD}$) indicate an absence of any significant differences in search rate which are attributable to the skill level of the subjects, thereby failing to support the third research hypothesis proposed at the outset of this chapter. Although on all 10 occlusion conditions the group differences were in the predicted direction of longer $\overline{FD}$s for experts, the effect is apparently a weak one.

Because of the range of skill group differences selected and the sample size used in this study one is therefore forced to be skeptical of accepting earlier propositions of visual search rate differences as being a particularly powerful and fundamental difference between the visual performance of experts and novices in sport tasks. Contrary to some of the earlier sport studies (e.g. Bard & Fleury, 1976a; Haase & Mayer, 1978) search rate was not found to differentiate clearly the visual search strategies of experts and novices. This again supports the contention made earlier that, although the visual search pattern may provide some indication of the perceptual strategies adopted by expert and novice performers, critical differences are established not so much in the search strategy used but rather in the performer's ability to extract relevant information from the display items fixated.

The $\overline{FD}$ parameter seems to reflect, for both groups, some of the concurrent changes in prediction certainty which occur as more visual information becomes available for analysis. In the temporal occlusion analysis $\overline{FD}$ decreases systematically as more visual information to aid
<table>
<thead>
<tr>
<th>Search Task</th>
<th>Study</th>
<th>Approximate Mean Fixation Duration (msec)</th>
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<tbody>
<tr>
<td><strong>I Tasks with Static Stimuli:</strong></td>
<td></td>
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</tr>
<tr>
<td>Reading</td>
<td>Andriesson &amp; de Voogd (1973)</td>
<td>200</td>
</tr>
<tr>
<td>Visual Inspection</td>
<td>Schoonard, Gould &amp; Miller (1973)</td>
<td>&lt;400</td>
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<tr>
<td></td>
<td>Megaw &amp; Richardson (1979)</td>
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<tr>
<td>Cathode Ray Tube Utilization</td>
<td>Sperandio &amp; Boujou (1983)</td>
<td>400-500 (mode)</td>
</tr>
<tr>
<td>Decision-making from Slide</td>
<td>Bard &amp; Pleury (1976a,b)</td>
<td>250-300</td>
</tr>
<tr>
<td>Stimuli</td>
<td>Haase &amp; Mayer (1978)</td>
<td>300 (novices) -420 (experts)</td>
</tr>
<tr>
<td><strong>II Tasks with Dynamic Stimuli:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Competitive Fencing</td>
<td>Bard, Guezennec &amp; Papin (1981)</td>
<td>615 (experts) -850 (novices)</td>
</tr>
<tr>
<td>Helicopter Control</td>
<td>Stern &amp; Bynum (1970)</td>
<td>715 (experts) -909 (novices)</td>
</tr>
<tr>
<td>Car Driving</td>
<td>Cohen (1978 b)</td>
<td>410 (on road) -520 (in lab)</td>
</tr>
</tbody>
</table>
response selection becomes available to the performer (Figure 110). This implicates a search phenomena whereby initially long fixations are used (as the extraction of information critical for the resolution of prediction uncertainty takes place) followed by an increased use of short duration fixations as the display is sampled to confirm existing predictions rather than to extract essentially new information. Although FD may be to some extent influenced by task difficulty the principal influence upon FD seems to be the time at which certain critical display cues become available, with FD being systematically influenced by conditions of temporal but not event occlusion manipulation (Figures 110 and 111).

The extent of the influence of task difficulty upon search rate (and specifically FD) can be assessed by comparing the FDs obtained from this experiment with FD from other tasks of different apparent difficulty. When such comparisons are made (Table 10) it is found that the FD for this task of approximately 590 msec is substantially longer than that generally seen in tasks where the display is relatively static but is within the range of FDs reported from tasks using dynamic stimuli. Although differences in FD between studies may be due, among other factors, to possible differences in the sensitivity of the eye movement recording instrumentation for detecting micro-saccades (Ohtani, 1971), the available data presented in Table 10 suggests that FD may, in some gross way, reflect task difficulty; FD being longer, and task difficulty greater, for the dynamic rather than the static stimulus tasks. If this is indeed the case then this particular film task would appear to provide
Figure 112: Fixation duration distribution for the expert group used in Experiment 2
Figure 113: Fixation duration distribution for the novice group used in Experiment 2

N = 18471
MEAN = 504.3 ± 2.5 MILLISECONDS
SD = 340.3 ± 1.8 MILLISECONDS
SKEWNESS = 1.773 ± 0.018
KURTOSIS = 4.487 ± 0.036
a task difficulty which is more akin to field tasks (e.g. Stern & Bynum, 1970; Bard et. al., 1981) than to some of the more artificial laboratory tasks (e.g. Bard & Fleury, 1976a) used earlier in the visual search analyses of sport. (This supposition will be examined in more detail in Chapter 6).

In order to obtain a comprehensive comparison of the temporal characteristics of the fixations utilized in this task with those used in other tasks, however, consideration of not only FD but also the distribution of the fixation durations is necessary.

(5) Fixation Duration Distribution Analyses

Skill Group Effects

The distribution of the durations of all fixations made by the expert performers and the novice performers are presented in Figures 112 and 113 respectively. In keeping with the earlier analyses it is apparent from these distribution plots that expert performers, on average, use longer fixations than novices in viewing the display but the extent of the FD variability within the groups prevents this effect from being a statistically significant one. For both skill groups the FD distribution is positively skewed with a greater proportion of relatively short FDs than fixations of above average duration. This positive skew in the FD distributions appears to characterize visual search activity for all manner of tasks and for all levels of performers (cf Schoonard, Gould & Miller, 1973, Figure 2; Megaw & Richardson, 1979, Figure 1; Bouma, 1978, Figure 11) and results in a positive correlation emerging between the distribution means and standard deviations (Megaw & Richardson, 1979).
Figure 118: Fixation duration distributions for the event occlusion conditions for the expert group used in Experiment 2
Figure 119: Fixation duration distributions for the event occlusion conditions for the novice group used in Experiment 2
In this data set this positive correlation is apparent in terms of the greater FD of the expert group carrying with it a concomitantly greater variance estimate (see Figures 112 and 113).

The observed distribution characteristics are those of a logarithmically derived function and consequently when a logarithmic rather than linear abscissa is used (Figures 114 and 115) the FD distributions of both groups can be seen to approach normality. Specifically the skewness and kurtosis indices approach zero and the positive mean: standard deviation correlation observed previously becomes suppressed.

(b) Occlusion Condition Effects

Figures 116 and 117 present the respective FD distributions of the expert and novice groups over each of the five temporal occlusion conditions, again illustrating the trend towards longer FDs for experts over all temporal occlusion conditions. More importantly though, for both skill groups, there is clear evidence of a shift in the distribution characteristics as more and more temporal information becomes available; specifically in the form of an increase in the relative frequency of shorter FDs as the time of occlusion is advanced from t1 through to t5. In support of the contentions made earlier from FDs alone it appears clearly that the fixations used early in the search sequence are, on average, relatively lengthy (as substantial information extraction is taking place) whereas later fixations tend to be primarily confirmatory in function, and subsequently of shorter duration. This increased
Figure 114: Logarithmic fixation duration distribution for the expert group used in Experiment 2
Figure 115: Logarithmic fixation duration distribution for the novice group used in Experiment 2

Novices
Combined males and females

Combined fixations
Combined cut-offs
Combined fh and bh
Combined ds and sm
Combined dl and cc

N = 18471
MEAN = 2.418 ± 0.002
SD = 0.267 ± 0.001
SKWNESS = 0.152 ± 0.018
KURTOSIS = -0.299 ± 0.036
Figure 116: Fixation duration distributions for the temporal occlusion conditions for the expert group used in Experiment 2
Figure 117: Fixation duration distributions for the temporal occlusion conditions for the novice group used in Experiment 2
prevalence of short duration fixations late in the search sequence results in a clear distribution shift to the left for later occlusion conditions and this particular transition in the emergent search pattern is apparent for both skill groups.

When the corresponding FD distributions are presented for the event occlusion conditions for the expert group (Figure 118) and the novice group (Figure 119) it is apparent, as with the earlier FD analysis (Figure 111), that event occlusion manipulations of task difficulty do not exert as powerful an influence upon FD characteristics as do the temporal occlusion conditions. Nevertheless, for both groups, a greater relative frequency of lengthy fixations is in evidence for the most difficult task condition (e1), where both racquet and arm information is occluded, suggesting an elongation of the FDs as the information at the usual fixation locations becomes unexpectedly difficult to extract. However this effect does not appear to be a particularly powerful or reliable one as occlusion of some cue sources known to be not critical to task performance (e.g. the opponent's head in condition e3 for the experts) also induce a distribution shift to the right relative to the control condition (e5).

(c) Fixation Location Effects

The FD distribution characteristics which emerge for fixations on different sections of the display are presented, collapsed across the two skill groups, in Figure 120. Positively skewed FD distributions are evident for all of the distinct fixation locations, with the cue source designated as carrying the highest information content (viz the racquet)
Figure 120: Fixation duration distributions for the different fixation locations for all subjects used in Experiment 2.
Figure 121: Fixation duration distributions for the different fixation locations for the expert group in Experiment 2.
Figure 122: Fixation duration distributions for the different fixation locations for the novice group in Experiment 2.
having, on average, the highest FD and the highest relative frequency of lengthy fixations. Cues of lower informational content (e.g. the feet, head and trunk) are sampled through the use of shorter duration fixations. These observations then support the notion of FD reflecting perceived information content (after Just & Carpenter, 1976) and support the observations made in the aircraft pilot studies of Papin et. al. (1980), that the relative frequency of lengthy FDs is highest for that location which has the highest search frequency and importance.

In relation to the stage of usage of each of the cue sources within the search sequence, it becomes apparent that fixations on the shuttle are generally of extremely short duration therefore supporting the notion that these fixations function mainly in a confirmatory manner. The observation of relatively short FDs for the feet, head and trunk cues early in the stroke sequence however is contrary to the previous observations of the use of more lengthy fixations at that stage of the event sequence. This therefore suggests that the earlier-observed effect is primarily a function of variations in the duration of racquet fixations across the stroke sequence.

For both the expert (Figure 121) and novice (Figure 122) groups similar relative distribution characteristics are evident for the different fixation locations - a greater frequency of lengthy fixations being evident for the racquet than for any of the other areas of the display. Interestingly again the observation of the utilization of more lengthy FDs by experts emerges across all of the fixation locations, as it did across all occlusion conditions (Figures 110 and 111), indicating
Figure 123: Fixation duration distributions for forehand and backhand strokes for all subjects used in Experiment 2.
Figure 124: Fixation duration distributions for down-line and cross-court strokes for all subjects used in Experiment 2.
Figure 125: Fixation duration distributions for smash and drop shots for all subjects used in Experiment 2.
that although the use of a lower search rate by experts is not a powerful discriminatory effect, it is, in this data set at least, a strikingly systematic one.

(d) Stroke Type Effects

Virtually identical FD distributions are evident when the subjects' visual search patterns for forehand and backhand strokes are compared (Figure 123). Although backhand strokes cause greater prediction difficulty to subjects from both skill groups (Figures 40 and 41), visual search of the backhand strokes is conducted at a comparable rate to that of the forehand strokes, arguing against the universal determination of FD by task difficulty, as suggested from some of the earlier analyses. As is the case with the forehand-backhand comparisons, the visual searching of strokes of different direction (i.e. cross court and down-the-line strokes, Figure 124) and of different force (i.e. smash and drop-shots, Figure 125) are conducted at basically comparable rates suggesting that search rate is apparently independent of stroke type.

As comparisons of the FDs for experts and novices across these different stroke types again reveals this non-significant yet systematic effect of extended FDs for experts, the following conclusion regarding the FDs utilized by subjects in this experiment seems justified. The duration of the fixations observed is determined primarily by the location of the fixation (being longer for the more critical racquet cues), the time of occurrence of the fixation within the search sequence (being somewhat longer earlier in the search sequence) and perhaps also,
Figure 126: Initial visual correction time as a function of the extent of temporal occlusion for the expert and novice groups in Experiment 2.

No significant differences are evident between data points.
but to a lesser extent, by the task proficiency of the subject (being somewhat longer for the expert badminton players). The type of stroke being viewed does not appear to influence the length of the fixations used.

To complete the analysis of the visual search parameters two final search characteristics occurring at opposite ends of the search sequence will now be examined. These parameters are visual correction time (VCT), which reflects the minimal time required to initiate the first saccade in response to the film display appearance and dwell time (DT), which reflects the extent to which foveation continues on the viewing screen after the film display has been occluded.

(6) Visual Correction Time Analyses

Figure 126 presents the VCTs for both the expert and novice groups for each of the five temporal occlusion conditions. Although the expert subjects display more rapid VCTs than those displayed by the novices across all the temporal occlusion conditions, neither these differences in subject proficiency ($F(1,29)=2.224, p>.05$) nor the occlusion conditions ($F(4,116)=1.435, p>.05$) significantly influence the time taken to make the first saccadic response to the display. Similarly VCT for the event occlusion conditions (see Figure 127) is also apparently not influenced by the subject's badminton playing capability ($F(1,29)=0.102, p>.05$) or the specific cue occlusion induced ($F(4,116)=2.213, p>.05$), as one would expect given the a priori nature of this measure. The time taken to make the initial eye movement is however significantly longer in the case of
Figure 127: Initial visual correction time as a function of the event occlusion conditions for the expert and novice groups in Experiment 2.

No significant differences exist either between groups or between conditions.
the event occlusion trials than the temporal occlusion trials ($F(1,29)=16.007, p<.05$) (e.g. compare the respective VCTs in the control conditions e5 and t3 shown in Figure 127) and this would appear to be a consequence, not of the specific content of these trials, but of the order in which the two conditions are presented. These differences suggest that by the time the event occlusion conditions are presented either some fatigue efforts have become active or there has been a decrease, as a consequence of task familiarity, in the subject's urgency in commencing the search process.

It appears, in view of its magnitude, that this VCT parameter essentially represents a simple reaction time (SRT) delay and this concurs with Yoshimoto et. al.'s (1982) observation of a high correlation between eye movement latency and reaction time in a selective eye-head co-ordination task. As soon as the film stimulus appears a saccade towards the film's central image (viz the opponent) is initiated, as in a typical SRT task, and viewed in this light the observation of systematically, but not significantly, faster VCTs for expert performers is readily interpreted (cf. the SRT comparisons of experts and novices given in Appendix A-1). The relatively low variabilities observed in VCT also support the notion of this parameter being a reflection of some in-built constraints in the mechanical ('hardware') properties of the visual system.

(7) Dwell Time Analyses

In contrast to the VCT parameter dwell time (DT) is an a posteriori parameter arising subsequent to, rather than prior to, the film display
Figure 128: Dwell time as a function of the extent of temporal occlusion for the expert and novice groups in Experiment 2.

Each adjacent occlusion condition is significantly different although there are no significant differences between the two skill groups.
Figure 129: Dwell time as a function of the extent of the event occlusion conditions for the expert and novice groups in Experiment 2.

No significant differences exist between the groups on any of the occlusion conditions.
presentation. Dwell time, the time the subjects remain on the screen after the display has been occluded, can be shown to be dependent upon the temporal occlusion task which is presented to the subjects ($F(4,116)=547.048, p<.05$) but to be independent of the skill level of the subjects ($F(1,29)=0.738, p>.05$) (See Figure 128). Specifically, with each successive gain in temporal information provided by adjacent temporal occlusion conditions there is a significant reduction in DT to the point, in condition $t5$, where the eye actually leaves the screen prior to film display occlusion. This therefore suggests some kind of relationship between DT and the apparent task difficulty.

The DTs also vary systematically across the different event occlusion conditions ($F(4,116)=18.647, p<.05$) with greatest DTs being apparent under those conditions where either the arm and racquet (e1) or the racquet alone (e2) are occluded (see Figure 129). More lengthy DTs are apparent under all five event occlusion conditions for the novices (indeed as was the case for the temporal occlusion trials) but these differences just fail to reach acceptable statistical levels ($F(1,29)=3.649, p=0.063$). The fact that longer DTs are observed on those trials which are completed with the greatest prediction error again supports the idea that the $a \text{ posteriori}$ DT parameter reflects the degree of task difficulty. This relationship between DT and prediction performance (as a measure of task difficulty) can be shown even more clearly by comparing the changes in DT which are attributable to specific cue occlusion (see Figure 130) with the corresponding changes in prediction error (refer again to Figure 79).
Figure 130: Increases in dwell time attributable to specific cue occlusion for the expert and novice groups in Experiment 2. (Increases are expressed relative to the control condition e5).

No significant differences exist between groups although for both groups e1 and e2 are significantly different from e3 and e4.
Significantly more lengthy on-screen fixations after display occlusion are attributable to the occlusion of both the arm (e1 causes greater increments in DT than all other conditions including e2) and the racquet (e2 causes greater increments in DT than either e3 or e4) and this mirrors the perceived importance of these cue sources as concluded from the radial error analyses. The only apparent discrepancy in these DT-radial error comparisons is that occlusion of visibility to the arm in addition to the racquet appears to induce more lengthy on-screen fixations for the novice group than for occlusion of the racquet alone, even though this additional arm information cannot be apparently used by this skill group in the prediction task (see Figure 79). It appears, therefore, that all subjects, when faced with a difficult task condition elect to maintain their visual attention on the screen for quite lengthy periods after the film occlusion in an attempt to utilize all of the available iconic persistence to enhance their stroke prediction.

Conclusions from Experiment Two

Visual search in the badminton film task appears to generally progress in the following manner.

(i) All subjects initially fixate in proximity to the screen centre at the completion of the inter-trial interval awaiting the appearance of the film trial information. The screen centre appears to be fixated because this area has the highest probability of containing the bulk of the opponent's body at the trial commencement and initial fixations are recognized to be
guided by the performer's a priori notions regarding the probable spatial location of relevant information.

(ii) Once the film information appears, the point of fixation is rapidly altered to coincide with general body features which provide information about the orientation of the opponent's body. This initial visual correction from screen centre (VCT) takes, on average, some 200-250 msec (roughly analogous to the SRT delays) and is usually performed slightly, though not significantly, faster by elite performers. Initial fixations in the search sequence appear to be directed in a fairly non-specific manner, towards cues providing generalized information about bodily orientation (e.g. the head, trunk and lower body) and these initial fixations are of relatively short duration, and are principally concerned with the extraction of early information regarding stroke development.

(iii) As the stroke develops from proximal force generation to distal limb displacement there is a corresponding proximal-to-distal alteration in cue dependency. Clearly the fixation location of highest priority appears to be the region surrounding the opponent's racquet and fixations upon the racquet account for some 60-70% of all fixations made. Not only is the racquet the most frequently fixated cue, but additionally fixations on the racquet also have the longest FD of all cue sources. Both these sources of evidence therefore clearly point to the racquet area as the predominant source of task relevant information. Although racquet area fixations occur throughout the whole
stroke sequence their relative durations vary according to their time of usage in the event sequence. Racquet fixations tend to be longest when the fixations occur early in the event sequence (implicating a relatively lengthy FD being associated with novel information extraction) and of shortest duration late in the event sequence (where these later fixations appear to serve primarily confirmatory functions).

(iv) When shuttle flight is available for relatively lengthy periods shuttle cues are also sampled foveally through the use of the saccadic eye movement system. The cues arising from the shuttle, like the later racquet cues, appear to act primarily in a confirmatory fashion to re-affirm or refine principal response selection decisions made much earlier in the event sequence. Accordingly shuttle FDs are typically short and visual monitoring of shuttle cues is often discontinued before all possible vision of shuttle outflight is occluded.

(v) In conditions where either the stroke sequence is occluded at an early stage (e.g. t1 - t3) or critical spatial cues are occluded (e.g. e1 and e2) the eye frequently remains fixated upon the screen centre for some time after cue occlusion as subjects attempt to utilize all available iconic persistence of visual information in order to facilitate their landing position predictions. The length of time the eye dwells on the screen centre prior to the saccadic movement of the eye away from the screen to the response sheet (DT) appears to reflect quite
accurately apparent task difficulty across the different occlusion conditions. The dwell times of novice players however, do not differ significantly from those of the expert players.

Overall, all subjects irrespective of their playing expertise in badminton, appear to adopt fundamentally similar visual search strategies in terms of the frequency with which they fixate different cue sources and the order in which this search proceeds. Despite expert performers utilizing systematically longer mean FDs, and a greater relative frequency of lengthy fixations (as evidenced from the FD distribution plots), across all occlusion conditions, stroke types and fixation locations, the visual search rate differences between experts and novices are not significant ones. This would appear to indicate, contrary to some earlier notions (e.g. Allen, Schroeder & Ball, 1978), that visual search rate (as implied from FDs) is not a particularly powerful factor discriminating the visual performance of the expert performer from the lesser skilled.

III: GENERAL CONCLUSIONS FROM EXPERIMENTS ONE AND TWO

In relation to the three working hypotheses proposed at the outset of this chapter regarding differences in the perceptual strategies of expert and novice performers it appears that the following conclusions are warranted from Experiments 1 and 2.

1) Hypothesis 1, concerning the expert's ability to utilize existing redundancy to extract earlier information than can the novice, appears to
be overwhelmingly supported. Comparisons of expert and novice performers across the five temporal occlusion conditions (Figure 24) clearly demonstrate a superiority of the expert performers in the extraction of early information to facilitate landing position prediction. The experts are apparently capable of extracting information in the time period $t_1 - t_2$ which the novices cannot utilize.

(ii) **Hypothesis 2**, the expert's use of different sources of information to those used by the novice, has also been supported on the weight of the evidence provided by the event occlusion analyses (see Figures 32 and 33). Different dependence on cue sources for information extraction are evident for experts and novices with the experts apparently utilizing information from cues arising from the opponent's arm - an area from which the novices can apparently extract no information. These differences in cue usage appear to exist even though fundamentally similar visual search patterns are adopted by both skill groups (compare Figures 102(a) and (b)), and this suggests that the differences in anticipatory performance between experts and novices are not so much in terms of differences in visual orientation to the display but are rather a consequence of the expert performer's greater capacity to extract information from some specific fixation locations. This difference between visual orientation and actual information extraction implicates a functional superiority for the occlusion technique over the eye movement recording technique, although the use of both procedures concurrently carries obvious advantages.

(iii) **Hypothesis 3**, that experts will search the display in a more
efficient manner through the use of a slower search rate, has not been supported. Despite the existence of systematically lower search rates across all task conditions the absence of significant group differences in FD in an experiment where the subjects are drawn from the extremes of the badminton playing-skill spectrum suggests that search rate is not a critical distinguishing feature of the elite performer.

Although these three hypotheses have been tested in a systematic manner there is still an obvious need to establish that these proficiency-related differences in perceptual strategy concluded above are reliable and robust ones and, moreover, that the methods used in reaching these conclusions are appropriate for making implications from the contrived laboratory setting to the true field setting. Although some evidence presented in the course of this chapter has supported the validity of the paradigm selected here for studying perceptual strategies in sport, the underlying issues of test reliability and validity still need to be addressed in more detail. Chapter 6 examines the reliability and validity of the conclusions of proficiency-related differences in perceptual strategy reached in this chapter through the use of a series of experiments in which the replicability of these findings is examined over time and across different response measures and in which the relative demands of the laboratory task and the actual playing situation are equated.

36. Specifically in support of the event occlusion approach it has been noted that the subject's search patterns are unaltered by selective event occlusion and that the use of occlusion procedures do not induce distraction effects (based on $t_3 - e_5$ comparisons). In support of the eye movement recording approach it has been noted that the fixation locations correspond well with the apparent attentional allocations of the subjects.
CHAPTER 6

EMPIRICAL EXAMINATION OF PARADIGM VALIDITY AND RELIABILITY

An obvious need exists in any developed test or acquired research paradigm to determine the validity and reliability of the dependent measures used, yet this is a frequently neglected procedure in many tests of motor behaviour (Safrit, 1978). Clearly in the case of the multi-procedural paradigm used in the experiments described in Chapter 5, evidence of the selected paradigm's validity and reliability would add substantial weight to the surety with which the derived conclusions could be regarded. Specifically it would appear desirable in terms of the selected paradigm's validity to be assured (a) that the laboratory-based task used imposes similar processing demands on the player as does actual playing and (b) that no interference to subject performance occurs through the use of the two concurrent data-extraction systems (i.e. simultaneous eye movement recording and film occlusion procedures). Similarly in terms of the paradigm's reliability it would appear desirable to be assured that the use of this multi-procedural paradigm with the same subjects results in the same conclusions being reached on each occasion the paradigm is utilized. Furthermore, in terms of assessing the robustness of the proficiency-related effects observed in Experiments 1 and 2 (Chapter 5), it is also desirable to demonstrate a persistence of these perceptual strategy differences across situations where different response measures are used and different skill group samples are utilized. This is necessary in order to verify that these proficiency-related differences in perceptual performance are generalizable ones and
not situation-specific ones.

The systematic assessment of these issues of procedural validity and reliability forms the basis of this chapter.

1 VALIDITY OF THE EXPERIMENTAL PARADIGM

The process of validation,

Narrowly considered, ... is the process of examining the accuracy of a specific prediction or inference made from a test score ... More broadly, validation examines the soundness of all the interpretations of the test - descriptive and explanatory interpretations as well as situation-bound predictions.

(Cronbach, 1971, p. 443).

A particularly important aspect of validation, known as content validation, involves ensuring that logical procedures are utilized in the test development and in this case this concern with content validity translates to the problem of ensuring that logical procedures are utilized in the selection of a paradigm for the assessment of perceptual strategies in sport. To this point the content validity of the paradigm used here has only been addressed indirectly in terms of careful consideration of relative strengths and weaknesses of possible procedures during the initial method selection process and in terms of careful attention to problems of laboratory simulation in the eventual construction of the film occlusion task (see Chapter 4). Further support for some of the issues of construct validity has also arisen in the previous chapter in that it has been demonstrated (a) in support of the construct validity of the occlusion paradigm, that the use of occlusion
mats on the film surface does not cause significant subject distraction from the task and (b) in support of the validity of the eye movement recording approach, that a close correspondence between visual orientation to cues and information content is evident for all subjects.

A number of key validity issues, in addition to those addressed indirectly in Chapters 4 and 5, still need to be addressed in a more direct manner however. These issues include:

(a) the extent to which ecological validity is retained in the selected laboratory paradigm
and (b) the extent to which the concurrent analysis systems of film occlusion and eye movement recording are independent.

Although no such simple measure as a validity co-efficient can be computed to assess content validity, in the same manner in which a reliability co-efficient can be used to assess test-retest reliability (Safrit, 1978), certain logical tests can be devised to make empirically-based inferences about these unresolved issues of paradigm validity. These devised tests of paradigm validity will now be examined.

(1) **Paradigm Validity in Terms of the Retention of Ecological Validity**

Although all attempts were made to preserve as much ecological validity as possible in the film task construction (e.g. through the use of appropriate, context-preserving stimuli; the imposition of realistic time constraints on the decision making process) inevitably some situation-specific information must be lost in the simulation process
(e.g. through disruption to auditory cues, use of two-dimensional displays, and use of a simplified motor response). In considering all these associated factors influencing ecological validity, the crucial issue appears to be the question of whether or not the task demands created in the laboratory provide a sufficiently close parallel to the demands of the real setting (i.e. actual badminton competition) for content validity to be preserved. A close laboratory-to-field parallel in terms of the demands placed upon the performer is obviously an essential requirement if the multi-procedural paradigm selected in Chapter 4, and utilized for data collection in Chapter 5, is to be seen to be a valid one.

**Procedures for Objective Assessment of Task Demands**

The best measure of the task demands facing the individual performer appears to be through the use of either the dual task or secondary task paradigms (Ogden, Levine & Eisner, 1979) in which subjects are required to perform two (or sometimes more) tasks simultaneously. In the dual task paradigm subjects are given no task priorities but are required to attempt to maximize their performance on both tasks, thus enabling some estimation of human performance capacities to be ascertained. The secondary task technique, on the other hand, requires subjects to give processing priority to the primary task to the extent that no differences in primary task performance are evident between the loaded condition, in which both tasks are performed, and the unloaded condition, in which only the primary task is performed. Comparison of secondary task performance can then be used in this paradigm to determine the attentional or
capacity demands of different tasks or different phases of the same task.
In both cases increased error or increased delays in responding to the
secondary task in the loaded condition can be taken as an indication of
high concurrent demands being placed on the information-processing
capacity of the performer by the primary task.

**Applications of the Secondary Task Paradigm**

Although the original theoretical notions (in which the secondary
task paradigm was developed) of the human operator as a single channel
system composed of sequential processing mechanisms (e.g. Senders, 1970)
has been modified in recent times to one in which the human performer is
viewed as a multiple resource allocation pool (see Navon & Gopher, 1980;
Wickens, 1980) the fundamental premises of secondary task methodology are
still tenable (e.g. see Chiles, 1977). For this reason the secondary
task method offers a potentially valuable insight into many applied motor
performance problems. Applied research using the secondary task paradigm
is usually considered to encompass any use of the technique in the
assessment of the "mental workload" imposed on the performer by any
particular set of task conditions (Trumbo, 1975) and the most frequent
applications of this procedure are in the assessment of specific task
workloads and in the assessment of performer automaticity.

A number of studies, both in ergonomic (Brown, 1962; Brown &
Poulton, 1961; Crosby & Parkinson, 1979; Damos, 1978; North & Gopher,
1976; Wetherell, 1981) and sport (Leavitt, 1979; Parker, 1977, 1981;
Vankersschaever, 1984) settings have demonstrated the presence of greater
"spare" capacity for expert performers, even in situations where no differences in primary task performance, are apparent. This greater spare capacity for the performance of subsidiary tasks appears to be a function of the expert's acquired primary task automaticity. This, in turn, is arguably a consequence of alterations in the mode of motor control with practice to one of feedback-independence (e.g., Schmidt & McCabe, 1976) and the associated transition of the majority of control to lower levels of the response hierarchy (Pew, 1966).

Secondary task performance, not surprisingly, seems quite amenable to practice effects (Damos et. al., 1981) and substantial increments in dual task performance occur quite rapidly with task-specific practice. Davids (1983), for example, has shown in a dual task study of ball catching that even the performance of 9 year old children can be brought to adult levels if extended practice is provided. Much of the acquired skill in both secondary- and dual-task performance appears to be a consequence of the selection of efficient response strategies (Welford, 1978) and this frequently manifests itself in an improved capability of the performers to effectively time share between concurrent tasks. Indeed a number of authors (e.g., Keele, 1982; Keele & Hawkins, 1982) have attempted to use this parameter of attentional flexibility as a criterion for the identification and assessment of skilled performance.

An alternative use of the secondary task paradigm is in the determination of attention demand fluctuations within tasks rather than the assessment of the demands between tasks or between different subjects on the same task. In the laboratory setting use of probe RT as a
secondary task with simple linear movements has lead to the conclusion that some movement phases, specifically pre-programming (e.g. Ellis, 1973; Glencross, 1980a; Glencross & Gould, 1979), initiation (e.g. Ellis, 1973; Posner & Keele, 1969) and error correction (e.g. Kerr, 1975; Posner & Keele, 1969; Zelaznik, Shapiro and McClusky, 1981), are more attention demanding than others, although the conclusions regarding attention demand locus appear dependent upon what modality the probe is presented through and whether attention demand is assessed relative to stimulus onset or response arrival (Girouard, Laurencelle & Proteau, 1984; McLeod, 1980). Some applications of secondary task technique to the examination of attentional demands across the time course of events in a number of sports skills have also been made.

Nettleton (1979, 1984), for example, has assessed the attention demands at various stages during performance on a coincidence-anticipation task designed to simulate the ball tracking skills common to sports tasks such as soccer. In keeping with many of the conclusions from the control of simple linear movements (especially the conclusions drawn by Posner & Keele, 1969), this study revealed that the demands of object tracking were greatest during the initial (predictive) and final (confirmatory) stages of motion, with the monitoring of the middle, essentially redundant, phases of object motion being relatively attention free. Although parallels can be drawn between performance on this coincidence-timing task and visual monitoring performance in some fast ball sports, implications must be drawn very carefully because of the reduced ecological validity of the task used (e.g. the unrealistically slow and uniform stimulus velocity; the predictability of the horizontal
flight path) and the failure to report primary task performance during the loaded conditions, thereby providing no indication of possible attentional switching and differential subject priorities (Davids, 1982). The problems of ecological validity can be easily resolved for the secondary task paradigm through probe RT implementation in the intact natural setting and a number of studies have taken this research tack.

Girouard, Perreault, Vachon and Black (1978) with high jumping, and more recently Barras (1984) with cricket batting, have examined attention demands across the time course of sports skills in field settings. Both studies have failed to reveal any systematic alterations in the pattern of attention distribution across the temporal expanse of these skills although the use of very small sample sizes, the failure to include control groups of novice subjects and the failure to closely monitor primary task performance appear as persistent methodological flaws. Recent examinations of the attention demands of simple catching tasks (Davids, 1983; Starkes, 1981), in which the trade-off of attention between the primary and secondary tasks is closely monitored, appear to indicate that, contrary to some of the earlier notions, attention demand is highest in the later stages of ball flight, especially just as the subjects are performing the grasping response. Most noticeably, however, comparisons of the attention demands across the time courses of 'real' sport skills and their laboratory simulation equivalents are not evident in the literature and this appears to be a substantial omission in view of the reliance which is continually placed upon laboratory tasks in the prediction and analysis of 'real' task performance.
The results obtained in all applications of the secondary task procedure, both in laboratory and natural field settings, appear to be substantially dependent upon the nature of the secondary task (Bingham, 1985; Ogden, Levine & Eisner, 1979) and for this reason, auditory probe RT, a task of known attention demand, is used in the following experiment to assess relative attention demands across the temporal expanse of both the laboratory paradigm (as used in Experiments 1 and 2) and an actual playing task equivalent. Different stimulus and response modalities are used for the primary and secondary tasks to avoid possible structural interference effects (Brown, 1968; Duncan, 1979; Kahneman, 1973) and the hypothesis is examined that the attention demands of both laboratory and field tasks (as assessed by probe RT) will show comparable and parallel magnitudes across the total (trial) sequence.

**EXPERIMENT 3**

**Method**

**Subjects** Eight expert racquet sport players, proficient to the level of A grade competitive standard in their specific sport, and eight novice racquet sport players, who were University undergraduate students, were selected as subjects for this experiment. Four males and four females were included in each of the skill groups.

**Apparatus** Probe RTs were obtained in this experiment by presenting an auditory tone stimulus through an amplifier system to the subjects and then recording the subjects' vocal response time using a remote microphone attached to the subjects' shirt collar. Probe presentations were controlled through the use of a 80 micro-computer connected in
Figure 132: Apparatus configurations for the field task used in Experiment 3.

Subjects in the field task were fitted with a lightweight microphone for the recording of auditory response times (top). Presentation and recording of probe RTs were made as for the laboratory task using, from left to right, a portable video camera, auditory transmitter, Z80 micro-computer and terminal and FM signal receiver (below).
Figure 131: Apparatus configurations and set-up for the laboratory task used in Experiment 3
series to an Esperit II terminal and keyboard and the collected probe RT data were initially recorded onto audio cassette and then later transferred to a PDP 11/34 minicomputer for analysis. The presentations of the probes in the film task were matched to specific film frames using the incremental frame counter output from the Lafayette 224-A-MK VII Data Analyzer projector, used to present the film task. In the field task probe presentations were controlled manually by the experimenter to match the stimulus presentation with specific events in the playing sequence (see Table 11).

In both the laboratory and field settings auditory probe presentation was also associated with the illumination of a concurrent light pulse which appeared out of the subject's field of view but within the field of view of a video camera used to record the whole experimental session. Examination of the video record of the experimental sessions of each subject allowed a calibration check to be made to ensure that the probe presentations coincided with the desired stimulus events in the stroke sequence either in the film display (for the laboratory task) or in the 'real' display of the playing (field) task. Apparatus configurations and illustrations of the experimental settings for both the laboratory and field tasks are given in Figures 131 and 132 respectively.

**Procedures** All subjects were tested with the secondary probe RT task during the performance of primary tasks set in two different test environments. These test environments were a field setting in which the primary task consisted of playing badminton against an opponent of
### TABLE 11

**Probe presentation positions for the respective laboratory and field tasks used in Experiment 3**

<table>
<thead>
<tr>
<th>Probe Positions</th>
<th>Laboratory Task</th>
<th>Field Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>During the waiting period prior to the opponent's stroke execution commencing</td>
<td>Immediately after the subject has struck the shuttle and the opponent's response execution has not commenced</td>
</tr>
<tr>
<td>2</td>
<td>In the middle of the foot movement and body positioning actions of the opponent prior to the racquet swing commencing</td>
<td>In the middle of the foot movement and body positioning actions of the opponent prior to the racquet swing commencing</td>
</tr>
<tr>
<td>3</td>
<td>In the middle of the opponent's backswing</td>
<td>In the middle of the opponent's backswing</td>
</tr>
<tr>
<td>4</td>
<td>In the middle of the opponent's downswing</td>
<td>In the middle of the opponent's downswing</td>
</tr>
<tr>
<td>5</td>
<td>2 frames after the opponent's contact with the shuttle</td>
<td>Immediately after the opponent has struck the shuttle</td>
</tr>
<tr>
<td>6</td>
<td>Midway through the inter-trial interval during the subject's pencil-and-paper response</td>
<td>During the subject's own stroke preparation and execution</td>
</tr>
</tbody>
</table>
consistent standard and a laboratory setting in which the primary task was to view a film of a badminton opponent and make predictions regarding the landing position of the opponent's stroke (as in Experiment 1). All subjects performed in both test environments with a minimum of one week separating the two test occasions. Half of the subjects in each group did the laboratory task first whereas the other subjects were tested initially in the field setting in order to counteract any possible order of presentation effects.

In each setting subjects were presented with 10 probe RT stimuli at each of six different probe positions, with the order of probe presentation varied randomly to prevent temporal anticipation by the subjects. The six probe positions were matched as closely as possible between the two test environments to facilitate comparison of probe RT's across the two primary task settings and these specific probe positions for the laboratory and field tests are listed in Table 11. In both test settings catch trials (i.e. primary task trials in which no associated secondary task occurs) were presented on 33% of occasions (after Salmoni, Sullivan & Starkes, 1976) so that temporal uncertainty was retained across all individual trials and probe positions. Within each setting the order of presentation of the unloaded (primary task only) and loaded (primary plus secondary task) conditions was counter-balanced to control for possible practice and/or fatigue effects on the primary task.

The following specific procedures were followed in each of the test environments:
Laboratory Test

Upon entering the test room subjects were fitted with the pencil microphone and 10 vocal SRTs (requiring subjects to respond 'now' as rapidly as possible after the auditory stimulus onset) were recorded. Variable foreperiods were used in these trials to suppress temporal anticipation. The subjects were then seated to face the film screen and instructed (as in Experiment 1) to observe the film of an opponent playing a series of badminton strokes, as if they were actually playing against the filmed opponent, and, for each stroke, to mark on a scaled representation of a badminton court where they perceived the shuttle would land.

After a series of practice trials subjects were given 40 test trials, in which no secondary task load was provided. (These were trials 001 - 040 in the film description given in Appendix B-2). After the 40th trial the projector was stopped and subjects were told that they would then be required to perform two tasks simultaneously - the primary task (as in the first 40 trials) and a subsidiary auditory task (as in the initial SRT condition). Subjects were instructed to give priority to the primary task and were warned against attempting to anticipate probe stimulus occurrence. A total of 80 trials were performed in this loaded condition (see Appendix B-2 for details of trials 041 - 120), with these 80 trials consisting of 10 repeat measurements in each of the six probe positions plus 20 catch trials in which no probe was presented. The probe presentations were controlled via micro-computer operating from pre-determined projector frame counts and the probe presentations were organized in such a manner that, despite their random order, each probe position was presented an equal number of times across all stroke types.
and an equal number of times for temporal occlusion conditions in which subsequent visual information was either available or not available following probe occurrence. Inter-stimulus intervals were great enough in all cases to circumvent any possible psychological refractory period effects. After the 120th trial the projector was again stopped and subjects were instructed to perform a further 40 film trials under conditions in which they were aware that no secondary task requirements would occur. (Again see Appendix B-2 for details of temporal occlusion trials 121 - 160). The total experimental session was videotaped and the accuracy of probe onset relative to film trial events was constantly monitored, using the light pulse onset as a basis for calibration (see again Figure 131).

(ii) **Field Test** The field test procedures essentially mirrored the order of testing utilized in the laboratory task with the period of secondary task testing being preceded and followed by extensive periods of primary task (playing) performance only. Specifically after initial warm-up activities, fitting of the remote microphone and stationary SRT recording, subjects were instructed to compete, in a rally situation, against a badminton opponent of A grade playing status in Brisbane Grade Fixtures. Some five to seven minutes of initial playing experience was provided before the secondary task requirement was introduced. The loaded condition continued until all 60 probe trials (10 in each of six different positions) were presented by the experimenter who, in this case, was responsible for the timing of the stimulus presentation. As before, the probe positions were presented in pre-specified random
orders, although, because of the natural variability occurring in the field task, the proportion of catch trials to test trials was somewhat higher than in the laboratory setting. The loaded condition was again followed by a further five to seven minutes of primary task only and, as for the laboratory task, the whole experimental session was videotaped in order to check the accuracy of probe presentation and to extract measures of primary task performance. Both this testing session and the laboratory testing session were of approximately 30 minutes duration.

**Analysis of Data** Primary task performance was evaluated for the laboratory task through the radial error discrepancy between the predicted and actual landing position (as per Experiment 1) and for the field task, from the video record, by assessing the percentage of unforced errors made by each of the subjects. Secondary task performance was assessed for both test environments using probe RT expressed either absolutely or as an increment relative to control values in the unloaded condition. Probe RT values were subjected to an analysis of variance using the between-group factor of subject expertise and the within-group factors of test setting and probe position and the sources of significant effects were isolated using the Newman-Keuls post-hoc procedure. Primary task performance between the loaded and unloaded conditions was also compared independently for the field and laboratory settings using analyses of variance.

**Results and Discussion**

Figure 133 presents the probe RTs as a function of probe position for each of the primary task settings. In this figure, as in all others
Figure 133: Probe reaction time as a function of probe position for the laboratory and field tasks for all subjects in Experiment 3.

Significant differences exist between the two test environments at probe positions 5 and 6.
in this section, probe RTs are plotted via the traditional stimulus arrival point procedure although it is recognized (after McLeod, 1980) that the true attentional peak probably occurs subsequent to the point of stimulus onset.

The most apparent feature of this initial analysis of secondary task performance is that both the loaded conditions produce substantially slower probe RTs than the unloaded condition, (i.e. the condition where the RT task is performed alone), indicating that both the task of playing badminton and its laboratory equivalent demand at least some of the performer's limited processing capacity. In other words neither task is performed "attention free" or automatically.

Comparison of the probe RTs between the test environments, the probe positions and the expert and novice groups follow.

Test Environment Comparisons Although no systematic main effect differences in the attention demand of the two test environments are evident ($F(1,14)=0.122, p>.05$), the extent of concordance between the respective attention demands of the laboratory and field tasks depends upon the stage of the event sequence at which the secondary probe is presented ($F(5,70)=5.712, p<.05$). Significant differences exist between the attention demands of the two test conditions at probe position 5 (where the attention demand of the field test is greatest) and at probe position 6 (where the attention demand of the laboratory task is greatest), with no differences being evident at the first four probe positions. These observed differences can be explained in the following
The field test has greater demand than the laboratory task at probe position 5 because of the additional necessity to organize a concurrent movement response. Subjects in the laboratory task have no necessity to organize a comparable gross motor response and are only occupied with the observation of, what is by that stage of the trial sequence, primarily redundant visual information. The delayed probe RT response of the subjects in the laboratory task for probe position 6, in contrast, appears to be an artifact of the response mode requirements of the laboratory task. Subjects in this experimental setting are forced to make a substantial visual re-orientation at trial completion from looking upwards at the screen to looking downwards at the response sheet (in order to record their landing position prediction) and this involves a substantial alteration of task attention - almost to the point where the viewing phase and the response phase virtually constitute different tasks. As a consequence, when a probe stimulus is presented during the inter-trial interval in the laboratory task probe RTs are excessively lengthy. In contrast in the field test the continuous rather than discrete nature of the trial sequences results in an essentially consistent attention demand across the whole task duration. Most importantly however, when the demands of both tests are principally perceptual (as they are when probes are presented in positions 1-4) the attention demands of both tests are comparable. This provides support for the validity of the laboratory task in terms of its simulation of the perceptual demands of the 'real' task.
**Probe Position Comparisons.** When the different probe positions are compared it becomes evident that attention demand is the same across all probe positions for the field task but not for the laboratory task. In the laboratory task the only difference in probe RT is a slower response for probes in position 6 compared to probes at earlier points (position 2, 3 and 5) and this appears to be merely an artifact of the delayed response which occurs when probes are presented during the laboratory inter-trial interval i.e. during the period when subjects are involved in the task of translating their landing position predictions onto paper. Overall attention demands, in this particular racquet sport at least, appear to be generally consistently high across the whole temporal sequence supporting observations made in the few earlier sport-specific studies available in the literature (i.e. Barras, 1984; Girouard et. al., 1978). This observation of uniformly high attention demand in movement perception is obviously contrary to many of the traditional conclusions reached regarding varying attention demands for the phases of movement control, although even these effects may be artificial and the true attention demand uniform across the movement duration (e.g. see Mcleod, 1980).

**Skill Group Comparisons.** Although no overall systematic group differences in probe RT are evident ($F(1,14)=2.737, p>.05$), there is a significant interaction between subject proficiency and the test setting ($F(1,14)=4.577, p<.05$) in this experiment and this necessitates the independent examination of the laboratory-to-field task probe RT comparisons for each group.
Figure 134: Probe reaction time as a function of probe position for the laboratory and field tasks for the expert group in Experiment 3.

No significant differences exist between the two test environments.
Figure 135: Probe reaction time as a function of probe position for the laboratory and field tasks for the novice group in Experiment 3.

Significant differences exist between the two environments at probe position 6 only.
The respective laboratory and field task probe RTs at each of the six probe positions are presented, for the expert group alone, in Figure 134. Expert racquet sport players appear to allocate their perceptual attention in basically the same manner for both the laboratory and field tests, with the laboratory task probe RTs essentially paralleling those of the field task for all positions except probe position 6. Although the probe RTs of the field test are consistently higher than for the laboratory test for probe positions 1 to 5 the test setting effect just fails to reach statistical significance ($F(1,17)=4.763, p=0.064$). Therefore, in the associated absence of any significant probe position ($F(5,35)=2.259, p>.05$), or test setting x probe position interaction effects ($F(5,35)=2.185, p>.05$), the conclusion must be made that the attention demands of the laboratory and field tests are comparable for expert subjects with, for both tests, essentially uniform attention demands being evident across the whole test sequence.

For novice racquet sport players (see Figure 135) the overall attention demands of the two test settings are also comparable ($F(1,7)=1.187, p>.05$) although the probe RT values do differ when the probes are presented at position 6 ($F(5,35)=3.921, p<.05$). As was the case with the main analysis of probe position effects (Figure 133), response to probes presented during the inter-trial interval in the laboratory test were significantly slower than the responses to comparably placed field test probes but again this would appear to be simply an artifact of the unique response demands of the laboratory task. As all of the stages in which visual search and perceptual information extraction occur exhibit comparable attention demands between the two
Figure 136: Probe reaction times as a function of probe position for the laboratory task for the expert and novice groups in Experiment 3.

Significant differences exist between the expert and novice groups under all of the dual task conditions.
tasks it would appear that, for this novice skill group also, one is again justified in concluding that the film test provides a reasonable simulation of the task demands of actual playing. For both test settings, with the exception of probe position 6 for the laboratory test, a conclusion of essentially uniform attention demand across the complete stroke duration (i.e. from the stage of perception of the opponent's stroke through to completion of the subject's own response) is reached.

When the two skill groups are compared directly on the two tests some differences in performer automaticity and in time-sharing strategy become evident. When experts and novices are compared on the laboratory task for instance (Figure 136), the experts show across all probe positions a significantly faster secondary task performance (F(1,14)=4.326, p=0.05), indicating the presence of the expected greater automaticity and spare attentional capacity usually associated with expert performance (e.g. Brown, 1962; Parker 1977). However, in view of the expert subject's faster vocal SRTs in the unloaded control conditions (F(1,14)=4.938, p<0.05) a more appropriate comparison of the two groups might be made by considering the change in probe RT induced by the primary task (rather than by considering absolute probe RT as the dependent measure) as the differences observed may be merely a consequence of the control condition differences.

When these differences in RT in the single (unloaded) conditions are taken into account overall group differences are no longer evident (F(1,14)=1.510, p>0.05) despite the systematically lower increments in probe RT experienced by the experts at all probe positions (see Figure
Figure 137: Increases in reaction time due to probe presentation expressed as a function of probe position for the laboratory task for the expert and novice groups in Experiment 3. (Increases are expressed relative to an unloaded SRT measure for each group).

No significant differences exist between the groups.
Figure 138: Increases in reaction time due to probe presentation expressed as a function of probe position for the field task for the expert and novice groups in Experiment 3. (Increases are expressed relative to an unloaded SRT measure for each group).

No significant differences exist between the groups.
Overall probe position effects are evident ($F(5,70)=7.362, p<.05$) and these are due, as expected, to a higher attention demand at probe position 6 than at all other positions but also to a lower increment in probe RT for probe position 5 compared to positions 1, 4 and 6. This latter difference would appear to indicate a low attention demand in the laboratory task when shuttle outflight is being viewed and this is to be expected when one considers the redundancy of much of the visual information presented at this stage and the absence of any urgency to produce a motor response, unlike the field test situation. These differences in probe position effects are the same for both skill groups ($F(5,70)=0.913, p>.05$).

Figure 138 presents the corresponding comparison of the increments in probe RT for the expert and novice group for the field task of actually playing badminton. As with the statistical conclusion reached for the laboratory (film) test, no differences in the changes of probe RT are evident for the expert and novice subjects in the field test situation either ($F(1,14)=0.517, p>.05$) and indeed in many instances the mean probe RTs of the experts are actually slower, though not significantly so, than those of the novices. Unlike the laboratory task however, no differences in the increments in probe RT for either group occurs as a function of the time of probe presentation ($F(5,70)=0.661, p>.05$).

The apparent absence of the expected superior secondary task performance for the expert subjects can be attributed to a number of factors. Firstly sampling difficulties in terms of (a) the selection of an expert racquet sport group rather than an expert badminton group (i.e.
Figure 139: Primary task performance for the laboratory task in the loaded (dual) and unloaded (single) test conditions for the expert and novice groups in Experiment 3.

No significant differences exist between the conditions for either group.
many of the subjects classified as experts had little or no specific badminton experience)\(^{37}\) and (b) the use of a relatively small sample size, may have detracted from the achievement of significant effects. This would appear to be especially pertinent in the case of the laboratory test (Figure 137) where the observed data trends were in the direction hypothesized. A more important methodological problem however would appear to be with controlling the time-sharing behaviour between the primary and secondary task to a comparable level for the two groups. Although subjects were instructed under both test conditions to give attentional priority to the primary task there appears to be skill group differences in the extent to which attention is actually shared between primary and secondary tasks. The respective primary task performances of the expert and novice groups under the loaded and unloaded conditions are shown in Figure 139 for the film task and in Figure 140 for the field task and this allows these proficiency-related differences in time-sharing strategy to be highlighted.

In the laboratory task both groups appear to give attentional priority to the primary task as instructed with the primary task performance (as measured by radial error) being comparable for both the loaded and unloaded positions \((F(1,14)=0.937, p>.05)\). When primary task performance is given priority and the groups display similar primary task competency, as they do in the laboratory test, differences in secondary task performance can be expected to reflect subject proficiency. Indeed

\(^{37}\) An expert badminton group was not used because of the sheer difficulty in gaining access to such a group.
Figure 140: Primary task performance for the field task in the loaded (dual) and unloaded (single) test conditions for the expert and novice groups in Experiment 3.

Significant differences exist between the conditions for expert but not novice subjects.
in the laboratory task secondary task differences are in the direction of greater spare attention for experts, as hypothesized, but statistical significance is not achieved, possibly because of the sampling problems discussed previously.

In the field setting, in contrast, the groups vary markedly in the extent to which they trade-off attention (and performance) between the primary task of playing and the secondary task of responding to the auditory probe (Figure 140). The strategy adopted by the novice players appears to be one in which playing (primary task) performance is reduced in the loaded task condition (as evidenced by a significant increase in unforced errors from the unloaded to the loaded condition; $F(1,14)=18.639, p<.05$) in order to be leave adequate spare attention to allow the secondary task to be performed with reasonable competence. Experts, on the other hand, appear to discern a direct relationship between attentional allocation and performance on the playing task (perhaps unlike the film task where increased attentional allocation may not have guaranteed improved task performance) and consequently allocate all attention to the playing task to the detriment of secondary task performance. Persistence with this strategy of giving maximal priority to the playing task is evident in the experts' comparable primary task performance across both the loaded and unloaded conditions ($p>.05$).

**Conclusions**

The following conclusions seem warranted from this experiment.

Firstly, for both tests the attention demand is high but essentially
uniform across the total trial duration. The only exception to this uniform demand is for the laboratory-based film task where probes presented during the subject's orientation to the response sheet, rather than to the film screen, reveal exceptionally slow RTs.

Secondly, there is some indication of experts performing both the laboratory and the field test with more spare attentional capacity than the novices but this effect is not clear because of the confounding effects of sampling difficulties and proficiency-related differences in the priority allocated to the primary task.

Thirdly, and most importantly, the attention demands of the perceptual stages of the laboratory and field tasks appear to be comparable, irrespective of the skill level of the subjects, thereby providing support for the validity of the laboratory paradigm as an indicator of perceptual performance in the natural setting.

(2) Paradigm Validity in Terms of the Independence of the Film Occlusion and Eye Movement Recording Procedures

It has already been observed in the previous chapter that the use of the film occlusion procedures does not appear to interfere with the visual search sequence, at least in the sense that no alterations in the search pattern were evident with selective occlusion of different critical cue sources (see Table 9). To complete the argument for paradigm validity in terms of the independence of the two concurrent data extraction systems it is also necessary to demonstrate that no converse interference in the occlusion task performances occurs as a consequence.
of the use of concurrent eye movement recording.

Experiment 4 examines the independence of the two data-extraction systems by comparing the occlusion task performance of subjects performing the film task both with and without concurrent eye movement recording.

EXPERIMENT 4

Method

Subjects Eight novice racquet sport players who were undergraduate students in Physical Education at the University of Otago served voluntarily as subjects in this experiment. Four of the subjects were males and four were females.

Apparatus As per Experiment 2.

Procedures Subjects performed the film occlusion task (as described in Experiment 1) under two test conditions - a condition in which subjects were required to wear the eye movement recording apparatus (see Figure 73) throughout the experiment and a condition in which concurrent eye movement recording was not performed and the head-mounted recording apparatus was not worn. The order of testing was counter-balanced between subjects (and across the gender of the subjects) and a minimum time of four weeks was required between the performance of the two test conditions. All other test procedures were as for Experiment 1.

Analysis of Data Radial error measures of the discrepancy between the actual landing position and the subject's prediction of the landing
Figure 141: Radial error in the prediction of the shuttle landing position as a function of the degree of temporal occlusion for subjects wearing and not wearing the eye movement recording apparatus in Experiment 4.

No significant differences are evident between the test conditions. For both test conditions significant reductions in radial error occur from t2-t3 and from t3-t4.
position were calculated using the procedures outlined earlier for Experiment 1 and comparisons were drawn on radial error between the two test conditions using analysis of variance procedures.

Results and Discussion  Figure 141 compares the prediction performance of the subjects on the five temporal occlusion conditions under the conditions where the eye movement recording apparatus was and was not worn. No differences in landing position prediction accuracy are evident between the two test conditions either overall \(F(1,7)=1.220, p>.05\) or on any of the five occlusion times \(F(4,28)=1.169, p>.05\), suggesting that wearing the eye movement recording apparatus in no way interferes with the task performance of the subjects. This therefore supports the notion of the independence of the two concurrent data-extraction techniques proposed earlier. Under both test conditions significant reductions in prediction error are evident when temporal information in the periods from \(t_2 \rightarrow t_3\) and from \(t_3 \rightarrow t_4\) is made available to the subjects \(F(4,28)=44.338, p<.05\), supporting the observations made earlier (see Figure 24) regarding the timing of critical information extraction for novice subjects.

As with the temporal occlusion analysis concurrent eye movement recording has no influence upon prediction accuracy on any of the five event occlusion conditions \(F(4,28)=2.289, p>.05\) (Figure 142) again supporting the construct validity of utilizing both eye movement recording and film occlusion procedures concurrently, in an attempt to examine sport-specific perceptual strategies. A main effect for event occlusion conditions is evident \(F(4,28)=14.715, p<.05\) and this is a
Figure 142: Radial error in the prediction of the shuttle landing position for the event occlusion conditions for subjects wearing and not wearing the eye movement recording apparatus in Experiment 4.

No significant differences exist between the two test conditions.
consequence of higher radial error when either the racquet (e2) or the racquet and arm (e1) information is disrupted in comparison to disruption of other potential cue sources (p<.05). Therefore these results concur with the previous observations of racquet importance as a cue source for novices (cf Figures 32 and 33), but more importantly these same conclusions are reached regardless of whether or not concurrent search pattern recording is being made.

Conclusions

Contrary to possible expectations based on the weight and potential discomfort associated with wearing the eye movement recording apparatus, and contrary to observations of suppressed task performance in some other search activities when concurrent eye movement recording is made (see Megaw & Richardson, 1979), there was no evidence from this experiment to indicate interference in prediction performance arising from the concurrent recording of eye movement patterns. Task performance was comparable on all 10 occlusion conditions regardless of whether subjects were wearing or not wearing the eye movement recording apparatus and this observation of the apparent independence of the two data-extraction systems adds further support to the validity of the paradigm constructed for use in Chapter 4 and utilized for skill-group comparisons of perceptual strategy in Chapter 5 (Experiments 1 and 2).

II: RELIABILITY OF THE EXPERIMENTAL PARADIGM

For a developed paradigm to be of use in any sphere of measurement, and for the results of studies using such paradigms to be credible, it is
necessary to establish not only the validity of the paradigm but also its reliability. Specifically, it is necessary, in order to support the reliability of the paradigm chosen in this thesis, to demonstrate that comparable results (and conclusions) can be derived from the paradigm on any occasion that it is used to examine the perceptual strategies of a particular subject or group of subjects.

In the experiments that follow the test-retest reliability of the dependent measures from both the film occlusion analyses (Experiment 5) and the visual search analyses (Experiment 6) are examined independently in order to assess the robustness of the conclusions drawn in Chapter 5 regarding information processing and visual search in racquet sports. Although this determination of test reliability would appear to be a fundamental step in evaluating the power of the conclusions drawn regarding proficiency-related differences in perceptual performance, it is of interest to note that none of the previous sport-specific applications of either the film occlusion paradigm or the visual search paradigm have reported reliability estimates. Only Thiffault (1980), in the development of a visual-perceptual test to measure the speed of tactical judgments in ice hockey players, based on slide presentations of sport-specific stimuli, has previously reported test-retest reliabilities.

EXPERIMENT 5

Method

Subjects Subjects in this experiment were 16 novice racquet sport players all of whom had previously participated in Experiment 1. This
experimental group consisted of equal numbers of male and female subjects.

**Procedures** All subjects performed the film task, as described in Experiment 1, on two separate occasions with the test-retest delay varying from a minimum of four weeks to a maximum of five weeks. The subject's initial test was used in the development of the data base reported in Experiment 1 and the re-test was undertaken on a voluntary basis, with subjects having received no follow-up results from the initial test or having had no badminton-specific practice in the interim. Half of the subjects (four males and four females) performed both tests with concurrent eye movement recording whereas the other subjects performed both tests without concurrent eye movement recording.

**Analysis of Data** On each performance of the film task the dependent measures of radial error, constant lateral error, absolute lateral error, constant depth error and absolute depth error were derived using the procedures outlined for Experiment 1. Reliability on each of these prediction measures was then assessed through both analysis of variance and correlational methods (see Marteniuk, 1974, pp. 103-130) in order to determine the extent to which (a) comparable conclusions are drawn each time the test is administered and (b) scores on different occlusion items parallel each other from one administration of the test to the next.

Repeated measures analyses of variance were performed to compare initial test and re-test scores, for each of the dependent measures, for the temporal and event occlusion conditions in turn. The purpose of
Figure 143: Radial error in the prediction of the shuttle landing position as a function of the degree of temporal occlusion for the initial and re-test conditions in Experiment 5.

No significant differences exist between the test occasions. For both tests significant reductions in error occur from t2-t3 and from t3-t4.
these comparisons was to assess the extent to which the same conclusions are reached each time the test is performed - comparable conclusions from each performance of the test by the same subject or group of subjects being an essential requirement of test reliability. Test-retest reliability co-efficients were also computed for all of the error measures and for all occlusion task conditions using Pearson's Product-Moment Correlation procedure. This procedure was used in order to assess the degree of concordance between error scores displayed by the subjects on the two separate test occasions.

Results and Discussion

(i) Radial Error Analyses Figure 143 displays the radial error in prediction as a function of the temporal occlusion conditions for the 16 subjects in both the initial test and the re-test. No differences in prediction performance are evident between the performance of the subjects on the initial test and on the re-test either overall ($F(1,15)=0.685, p>.05$) or on any of the five temporal occlusion conditions ($F(4,60)=0.883, p>.05$). In both the initial test and the re-test significant increments in prediction accuracy are only evident when temporal information is incremented from $t2 - t3$ or from $t3 - t4$ ($F(4,60)=108.420, p<.05$), with no changes in radial error being evident from $t1 - t2$ or from $t4 - t5$. These observations are in keeping with all other temporal occlusion analyses of novice racquet sport players.

38. It is recognized however that the use of analysis of variance in this case in an attempt to support rather than reject the null hypothesis does bias the statistical test in favour of concluding that similar rather than different results have been achieved.
No significant differences exist between the tests on any of the occlusion conditions.
performed throughout the course of this thesis (e.g. see Figures 24 and 141). Most importantly it becomes evident that the conclusions drawn regarding the temporal occurrence of critical information for stroke prediction by novice badminton players are identical on each occasion the film task is presented and this observation is highly supportive of the reliability of the temporal occlusion procedure.

As was the case with the temporal occlusion trials no differences in prediction performance, as assessed via radial error, are evident between the initial test and the retest for any of the five event occlusion conditions \( F(4,60)=1.539, p>.05 \) (see Figure 144) with, in both tests, the radial error for racquet and arm occlusion (e1) and racquet occlusion alone (e2) being greater than for all other conditions \( F(4,60)=12.333, p<.05 \). As the radial error on these two occlusion conditions is not significantly different \( (p>.05) \), the consistent conclusion is reached on both test occasions, as it was previously (Figure 32), that the racquet is the principal source of anticipatory information for novice subjects. Similarly no differences in distractability, as evidenced by differences between the control conditions of irrelevant occlusion (e5) and no occlusion (t3), are evident between the two test administrations \( F(1,15)=0.172, p>.05 \).

When event occlusion difference scores are plotted (Figure 145) the same statistical conclusions are also reached regarding cue usage on each occasion. No differences in radial error change due to cue disruption are evident between the 2 test occasions for any of the cues \( F(3,21)=0.683, p>.05 \) with the common conclusion being that occlusion of
Figure 145: Increases in radial error in the prediction of the shuttle landing position attributable to specific cue occlusion for the initial and re-test conditions in Experiment 5. (Increases are expressed relative to the control condition e5).
vision to both the arm and the racquet together disrupts prediction performance significantly more than does either head or lower body occlusion \((F(3,21)=4.568,p<.05)\).

Prediction performance of the subjects, as measured by radial error, is therefore remarkably consistent across different test occasions for both the temporal and event occlusion conditions. Identical conclusions are reached for this group in each case regarding the time at which critical prediction information is extracted (temporal occlusion) and the specific cues used for the extraction of anticipatory information (event occlusion) and this replicability of conclusions strongly supports the reliability of the developed film occlusion paradigm. Surprisingly prior exposure to the test does not appear to facilitate repeat performance of the test in any way (9 of the 16 subjects actually show inferior prediction performance in the re-test relative to the initial test) although this is perhaps to be expected in view of the known importance of knowledge of results in the improvement of task performance (e.g. Bilodeau, Bilodeau & Schumsky, 1959; Newell, 1974b).

Given that overall prediction accuracy assessed by radial error appears to be a reliable measure a second important issue is the extent to which both its lateral and depth components are equally reliable. Assessment of the reliability of these component error measures is important in view of the critical role they have been assigned in Experiment 1 in the differentiation of errors related to the independent judgment of stroke direction and strength.

(ii) **Lateral Error Analyses** When the unsigned absolute lateral
Figure 146: Absolute lateral error in the prediction of the shuttle landing position as a function of the degree of temporal occlusion for the initial and re-test conditions in Experiment 5.

No significant differences exist between the test occasions. For both tests significant reductions in error occur from t2-t3 and from t3-t4.
Figure 147: Absolute lateral error in the prediction of the shuttle landing position as a function of event occlusion for the initial and re-test conditions in Experiment 5.

No significant differences exist between the tests on any of the occlusion conditions.
Figure 148: Increases in absolute lateral error in the prediction of the shuttle landing position attributable to specific cue occlusion for the initial and re-test conditions in Experiment 5. (Increases are expressed relative to the control condition e5).

No significant differences exist between the two tests.
error measure is considered there is remarkable consistency in the performance of the group from the initial test occasion to the re-test (see Figure 146). No differences in the prediction of shuttle flight direction are evident between the two test occasions for any of the temporal occlusion conditions ($F(4, 60) = 0.571, p > .05$). On each occasion the conclusion is reached (as it was in the earlier analysis for the total novice group; Figure 25) that the critical time for the reduction of directional uncertainty is in the period from 2 frames prior to contact to 2 frames subsequent to contact ($F(4, 60) = 308.684, p < .05$) with no additional reductions in uncertainty being available either before ($t1 - t2$) or after ($t4 - t5$) this critical period.

When the event occlusion condition is re-tested no differences are evident between the performance of the subjects compared to the initial test on any of the occlusions either when performance is expressed in absolute terms ($F(4, 60) = 0.995, p > .05$; see Figure 147) or in comparative terms ($F(3, 21) = 0.558, p > .05$; Figure 148). On both test occasions occlusion of racquet cues (e1 and e2) produces significant increments in absolute lateral error relative to the control condition (e5) ($F(4, 60) = 33.141, p < .05$) and the constant conclusion is reached from both analyses that the racquet is the critical source of anticipatory information regarding forthcoming stroke direction for this particular novice group.

When the direction of the lateral errors committed (i.e. constant lateral error) is also considered a similarly high degree of replicability becomes evident across the different test occasions. As
Figure 149: Signed lateral error in the prediction of the shuttle landing position as a function of the degree of temporal occlusion for the initial and re-test conditions in Experiment 5.

No significant differences exist between either test occasions or occlusion conditions.
Figure 150: Signed lateral error in the prediction of the shuttle landing position as a function of event occlusion for the initial and re-test conditions in Experiment 5.

No significant differences exist between the two tests.
Figure 151: Absolute depth error in the prediction of the shuttle landing position as a function of the degree of temporal occlusion for the initial and re-test conditions in Experiment 5.

No significant differences exist between the test occasions. For both tests error on condition t3 differs significantly from all other occlusion conditions.
Figure 152: Absolute depth error in the prediction of the shuttle landing position as a function of event occlusion for the initial and re-test conditions in Experiment 5.

No significant differences exist between the two tests.
Figure 153: Increases in absolute depth error in the prediction of the shuttle landing position attributable to specific cue occlusion for the initial and re-test conditions in Experiment 5. (Increases are expressed relative to the control condition e5).

No significant differences exist between the two tests.
with the absolute lateral error measure no significant differences in the direction of the lateral errors are evident between the initial test and the re-test on any of the temporal occlusion conditions ($F(4,60)=0.525, p>.05$; see Figure 149) or on any of the event occlusion conditions ($F(4,60)=0.662, p>.05$; see Figure 150). Again the consistencies in the data obtained and in the conclusions reached regarding directional error across the two test occasions support, in the strongest terms, the reliability of both signed and unsigned estimates of directional prediction error and the reliability of the film occlusion paradigm in general.

(iii) Depth Error Analysis. The plots of absolute depth error as a function of the time of information occlusion are also parallel for both the initial test and the re-test (see Figure 151) with no significant differences in depth prediction being evident between the two tests on any of the temporal occlusion conditions ($F(4,60)=1.176, p>.05$).

Similarly for all event occlusion conditions (see Figure 152) no performance differences emerge in absolute depth error between the initial test and the re-test ($F(4,60)=1.260, p>.05$) and this replicability of results also extends to when absolute depth error is considered as a consequence of specific cue disruption through the expression of event occlusion difference scores (see Figure 153; $F(3,21)=1.738, p>.05$). In all film occlusion conditions therefore it appears that reliable assessment of absolute depth prediction error can be obtained through the use of the selected occlusion paradigm.
Figure 154: Signed depth error in the prediction of the shuttle landing position as a function of the degree of temporal occlusion for the initial and re-test conditions in Experiment 5.

No significant differences exist between the test occasions. For both tests significant changes in error occur from t4-t5.
Figure 155: Signed depth error in the prediction of the shuttle landing position as a function of event occlusion for the initial and re-test conditions in Experiment 5.

No significant differences exist between the two tests.
When signed depth error is computed, in order to determine the extent to which landing distance is under- and over-estimated for different occlusion conditions, evidence of high reliability is also forthcoming. Although the novice subjects consistently overestimate the landing position of the shuttle (possibly as a consequence of both their non-familiarity with shuttle flight characteristics and the disruption to stereoptic depth perception cues caused by the use of a film media presentation) this depth prediction bias occurs in a reliable fashion, being evident on both test occasions. On both temporal occlusion \((F(4,60)=0.570, p>.05)\) and event occlusion \((F(4,60)=0.760, p>.05)\) conditions no differences in initial-to-retest depth prediction error are evident for any of the specific occlusion conditions supporting the derivation of identical conclusions on each instance that the test is administered.

High replicability, therefore, has been demonstrated across test occasions for all 5 prediction error measures for both the temporal and event occlusion sections of this constructed test of perceptual strategies. In all some 13 independent analyses of variance have been performed, involving the comparison of the initial test and re-test on some 62 different occlusion condition x error measure comparisons. Remarkably not one of these comparisons has indicated the presence of a significant difference between the two test occasions supporting strongly the reliability of the film occlusion paradigm and its associated error measures and adding strongly to the conviction with which the conclusions drawn from Experiment 1 can be advanced as replicable and robust ones.
(iv) **Correlation Analyses** In order to further support this position regarding the reliability of the developed paradigm, and to alleviate any possible concerns regarding the use of analysis of variance procedures in the assessment of reliability, test-retest reliability co-efficients were also computed for each of the occlusion conditions and for each of the dependent error measures. A summary of these principal test-retest correlations is presented in Table 12.

Similar test-retest correlation co-efficients are evident for each of the 3 unsigned error measures (radial error, absolute lateral error and absolute depth error are all in the 0.55 - 0.65 range) and for each of the signed measures (i.e. constant lateral error and constant depth error are each in the order of 0.80) indicating that the extent of test-retest reliability is quite consistent across the different derived measures of prediction accuracy. (The greater correlation observed for the signed error measures is probably a consequence of the greater range of values over which it is possible to establish a relationship between the two score sets).

Using the procedures outlined by Morehouse and Stull (1975, pp. 199-200) it is evident that all obtained correlation co-efficients differ clearly from 0.00 (e.g. the lowest co-efficient of 0.557 for absolute depth error on temporal occlusion yields a t-value of 34.49 whereas the critical t-value is only 1.96) and using the co-efficient of determination it can be concluded that some 35-65% of the variance evident in the re-test error scores can be accounted for by performance on the initial test. Caution is apparently necessary however in using
Table 12

Test-retest correlations for the five measures of prediction error for the temporal and event occlusion conditions in Experiment 5

<table>
<thead>
<tr>
<th>PREDICTION ERROR MEASURE</th>
<th>TEMPORAL OCCLUSION</th>
<th>EVENT OCCLUSION</th>
<th>OVERALL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial Error</td>
<td>0.59</td>
<td>0.61</td>
<td>0.60</td>
</tr>
<tr>
<td>Absolute Lateral Error</td>
<td>0.63</td>
<td>0.63</td>
<td>0.63</td>
</tr>
<tr>
<td>Signed Lateral Error</td>
<td>0.79</td>
<td>0.82</td>
<td>0.81</td>
</tr>
<tr>
<td>Absolute Depth Error</td>
<td>0.56</td>
<td>0.61</td>
<td>0.58</td>
</tr>
<tr>
<td>Signed Depth Error</td>
<td>0.79</td>
<td>0.80</td>
<td>0.80</td>
</tr>
</tbody>
</table>
### TABLE 13

Test-retest correlations for radial error for each of the temporal (TO) and event occlusion (EO) conditions in Experiment 5

<table>
<thead>
<tr>
<th>TEMPORAL OCCLUSION</th>
<th>EVENT OCCLUSION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Condition</strong></td>
<td><strong>Correlation</strong></td>
</tr>
<tr>
<td>t1</td>
<td>0.52</td>
</tr>
<tr>
<td>t2</td>
<td>0.57</td>
</tr>
<tr>
<td>t3</td>
<td>0.53</td>
</tr>
<tr>
<td>t4</td>
<td>0.59</td>
</tr>
<tr>
<td>t5</td>
<td>0.61</td>
</tr>
</tbody>
</table>
this square of the correlation co-efficient to assess reliability (see Safrit, 1978, p. 142).

Although this particular test has lower test-retest reliability than tests of simple reaction time for example, (e.g. see Eckert & Eichorn, 1976; Haywood & Temple, 1976) this is to be expected when one considers the greater potential sources of both individual difference and error variance available in the film test. The possible contribution of measurement error has not been partitioned out of the current reliability estimate (see Henry, 1959), and this undoubtedly suppresses the impression of test reliability which can be currently gained. Despite the trading off of some test reliability in the attempt to develop a more ecologically valid test, the current film occlusion paradigm still displays test-retest correlation co-efficients of the magnitude of those reported for most standard tests of games skills (e.g. see Thorpe & West, 1970) and is comparable to that reported by Thiffault (1980) with his visual test of ice hockey decision-making skills. The test-retest correlations for the individual subjects range from 0.431 to 0.784 ($\bar{X} = 0.591, s = 0.120$) indicating that, for even the poorest case of replicability, a substantial portion of re-test performance is predictable from the initial test assessment. The extent of the score reliability between the two test occasions also does not appear to be influenced by relative task difficulty - the correlation co-efficients for all 10 occlusion conditions for radial error, for example, lying between the values of 0.50 and 0.60 (see Table 13).
Conclusions

Despite the known limitations in the use of the Pearson product-moment correlation in the assessment of reliability (Feldt & McKee, 1958; Kroll, 1962; Safrit, 1978, p. 140) and the design problems in using non-significant analyses of variance to support score similarity, the following conclusions seem justified regarding the reliability of the film occlusion paradigm.

Firstly, both the temporal and event occlusion approaches seem to be reliable in that identical conclusions are drawn from the analyses of variance on each occasion the test is administered regardless of what error measures are utilized.

Secondly, use of the Pearson product-moment correlation co-efficient also reveals relatively high test-retest reliabilities across all 10 occlusion conditions and for all five error measures with relatively large proportions of retest task performance being predictable from initial performance on the film task.

Both assessments of data set replicability therefore support the film occlusion procedure's capability to produce results of high reliability and this observation of paradigm reliability obviously adds strength to the conclusions reached in the first experiment regarding both the time at which critical cues are extracted (from the temporal occlusion analyses) and the sources of this anticipatory information (from the event occlusion analyses). It needs to be noted, however, in recognition of the experiment's limitations, that the occlusion procedure's reliability has only been demonstrated for subjects with no
prior badminton experience and that the expected parallel reliability for experienced racquet sport players has not been actually demonstrated experimentally.

The extent to which comparable reliability can be obtained from visual search parameters, and hence the extent to which the conclusions drawn from Experiment 2 can be expected to be replicated, is examined in Experiment 6.

EXPERIMENT 6

Method

Subjects Four novice badminton players, all of whom had previously participated in Experiment 2, were selected as subjects. Of these four subjects two were male and two were female.

Procedures All subjects performed the film task, as described in Experiment 1, on two separate occasions with eye movement recording being made in both instances. (For description of the eye movement recording procedures see Experiment 2). As with Experiment 5 no feedback was provided to the subjects regarding either their task performance or their visual search patterns from the initial test and a minimum period of four weeks elapsed before the re-test was performed.

Analysis of Data Data regarding the location, duration and order of ocular fixations for each trial on each test occasion was derived using the procedures described in Experiment 2 and the reliability of each of these search pattern parameters was assessed using both analysis of
Figure 156: Percentage of trial time allocated to each fixation location for the initial and re-test conditions in Experiment 6. (Calculation is based on all t5 trials.

No significant differences exist between the two tests.
variance and test-retest correlation procedures as in the previous experiment. In this way assessment was made, of (a) the extent to which comparable conclusions could be reached regarding each eye movement parameter on each occasion the test was administered and (b) the extent to which similar visual search patterns were utilized by the subjects on each occasion they were faced with the same test items.

Results and Discussion

(1) Fixation Location Parameters. Figure 156 presents the mean percentages of trial time allocated to each fixation location for the initial test and the re-test conditions. Under both test conditions remarkably similar allocation of foveal vision to the available display features is noted with the racquet region on both test occasions receiving by far the greatest proportion of ocular fixations. No significant changes in temporal allocation to any of the seven identified fixation locations are evident from the subjects' first exposure to the film task to their second (see Appendix L) and this supports the conclusion of unaltered cue usage derived from the prediction error measures in Experiment 5 (see especially Figure 145). The eye movement recording approach, in conjunction with the film task, therefore appears to provide a reliable and replicable indication of the location characteristics of the subject's visual search performance with the subject's scanning priorities being apparently unaltered by familiarity with the film task. Consistent conclusions regarding cue usage are drawn on each occasion fixation locations are recorded during the performance of the film task.
Figure 157: Mean fixation duration as a function of the degree of temporal occlusion for the initial and re-test conditions in Experiment 6.

No significant differences exist between the test occasions. On both tests the only significant differences in Fixation Duration are between t1 and t5.
Mean fixation duration as a function of event occlusion for the initial and re-test conditions in Experiment 6.

No significant differences exist between the two tests.
TABLE 14

Test-retest correlations for mean fixation duration for each of the temporal (TO) and event occlusion (EO) conditions in Experiment 6

<table>
<thead>
<tr>
<th>TEMPORAL OCCLUSION</th>
<th>EVENT OCCLUSION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition</td>
<td>Correlation</td>
</tr>
<tr>
<td>t1</td>
<td>0.41</td>
</tr>
<tr>
<td>t2</td>
<td>0.50</td>
</tr>
<tr>
<td>t3</td>
<td>0.56</td>
</tr>
<tr>
<td>t4</td>
<td>0.47</td>
</tr>
<tr>
<td>t5</td>
<td>0.45</td>
</tr>
<tr>
<td>All TO trials</td>
<td>0.49</td>
</tr>
</tbody>
</table>

OVERALL TEST-RETEST CORRELATION = 0.41
(II) **Fixation Duration Parameters** The visual search rates used by the subjects in both their initial test and in their re-test performance are shown in Figures 157 and 158. These search rates, as given by the FD parameter, are expressed as a function of the temporal occlusion and event occlusion conditions respectively. Pearson product-moment test-retest correlations for the FD parameter for each of the 10 film occlusion conditions are also provided in Table 14.

Although there are no significant changes in FD from the initial test to the re-test for the subjects' viewing of either the temporal occlusion ($F(1,3)=0.095, p>.05$) or the event occlusion ($F(1,3)=0.258, p>.05$) tasks, there is an overall trend evident on 9 of the 10 film occlusion conditions for the FD to be longer under the re-test conditions. With task familiarity therefore, there appears to be some indication of a slightly reduced visual search rate although this effect is neither strong enough to reach levels of statistical significance nor is it accompanied by any concomitant improvement in task performance (see Experiment 5). The search rates used, especially across the event occlusion task conditions, appear quite variable on a trial-to-trial basis and the test-retest correlations evident for the FD parameter are not particularly high (see Table 14).

The reliability of search rate parameters assessed in this manner is substantially less than the reliabilities observed for either the fixation location parameters or for the prediction error measures derived from the film task (cf Tables 12 & 13). Apparently although the percentage of time allocated to each cue source remains similar from one
Figure 159: Fixation duration distributions for the initial and re-test conditions used in Experiment 6. (Note the FDs plotted here are based on all t5 trials - the only one of the 10 occlusion conditions (see Figure 157) in which FD for the initial test is greater than the FD for the re-test).
test occasion to the next there may be considerable variability in the FDs, and hence in the rate at which the display is searched. These alterations in search rate with task familiarity do not however appear to influence in any way the subject's ultimate task performance. Logically then the fixation location and search order characteristics may be more potent influences of visual search performance than is the search rate, and this once again brings into question the importance which has previously been placed upon search rate as a distinguishing characteristic of the visual search of the expert performer (e.g. see Bard & Fleury, 1976a; Bard, Fleury, Carrère & Hallé, 1980). It is obviously difficult to maintain search rate as a distinguishing individual characteristic when the search rates are subject to considerable intra-subject variability in addition to inter-subject differences.

The observation that the search rate parameters for subjects performing this film task are somewhat variable from one test occasion to the next, and hence somewhat unreliable, are also in keeping with a number of ergonomic studies (e.g. de Terssac, Queinnec & Thon, 1983; Marquie & Cellier, 1983; Stern & Bynum, 1970) showing fluctuations in search rate parameters across the course of a work task or a work day. Trial-by-trial fluctuations in FD do not however alter the FD distribution characteristics substantially and similar positively skewed distributions are evident for both initial and re-test conditions in this experiment (Figure 159).

(iii) **Search Order Characteristics** Analysis of the percentage of
occurrences in which each fixation location preceded and was itself preceded by each and every other fixation location (see Appendix L) revealed that essentially similar search order characteristics were preserved by the subjects from the initial test through into the re-test. Regardless of the extent of task familiarity fixations on gross bodily features of the opponent (such as the head, trunk or occasionally the feet) occurred with highest probability early in the search sequence whereas fixations on the racquet and the subsequent shuttle outflight were dominant in the latter stages of search. On both the initial test and on the re-test by far the highest frequency of fixations was reported for the racquet region with this cue being dominant to the extent that the highest probability of subsequent fixation from any other display cue was to this region.

The subject's adherence to an essentially proximal to distal search order, with a racquet head priority, on both test occasions suggests that the subjects adopt a relatively consistent search strategy in their attempts to extract anticipatory information from the dynamic display presented by their opponent. This observation of general search order consistency is compatible with a number of the fundamental notions underlying models of recognition, such as the 'feature-ring' model of Noton & Stark (1971).

(iv) **Other Search Parameters** It was proposed in Chapter 5 that visual correction time provides an indication of the subject's saccadic response time to the onset of film information and is an essentially 'hard-wired' attribute showing many similarities to manual SRT. As an
Figure 160(a): Initial visual correction time as a function of temporal occlusion for the initial and re-test conditions used in Experiment 6.

No significant differences exist between either test occasions or occlusion conditions.
Figure 160(b): Initial visual correction time as a function of event occlusion for the initial and re-test conditions used in Experiment 6.

No significant differences exist between the two tests.
essentially a priori aspect of the visual search process VCT was shown in Experiment 2 to be relatively uninfluenced by specific film task conditions. In this experiment VCT was again shown to be unaffected by either the temporal \( F(4,12) = 0.943, p > 0.05 \) or the event \( F(4,12) = 0.938, p > 0.05 \) occlusion conditions, although there was some indication of the first saccadic response being made less rapidly under the re-test conditions (see Figure 160). Significant changes in VCT from the initial test to the re-test were not apparent for either the temporal occlusion conditions \( F(1,3) = 0.338, p > 0.05 \) or the event occlusion conditions \( F(1,3) = 0.094, p > 0.05 \) however.

The overall test-retest correlation for this parameter was particularly low \( r = 0.22 \) indicating that this parameter is not a 'hard-wired' constant attribute of the individual performer's search pattern as originally conceived. It appears rather to be a variable feature influenced by a number of extraneous factors, such as the proximity of the existing fixation to the player's body centre at the moment of film appearance.

At the other end of the search sequence dwell time (DT), the time between film occlusion and the subject's final saccadic movement off the screen, appears to be a somewhat more reliable parameter. On both the initial test and the re-test DT reflects closely the task difficulty as manipulated by varying the point of temporal occlusion (see Figure 161a) with, on both test occasions, DT being significantly reduced with each increase in temporal information supplied to the subjects \( F(4,12) = 215.17, p < 0.05 \). Manipulation of task difficulty through event
Figure 161(a): Dwell time as a function of temporal occlusion for the initial and re-test conditions used in Experiment 6.

No significant differences exist between test occasions. For both test occasions significant differences exist between each adjacent occlusion condition.
Figure 161(b): Dwell time as a function of event occlusion for the initial and re-test conditions used in Experiment 6.

No significant differences exist between the two tests.
occlusion (Figure 161b) exert a less powerful influence upon DT with no significant differences in DT, on either test occasion, occurring across the different event occlusion conditions ($F(4,12)=0.805, p>.05$). Consistent conclusions are therefore reached from the DT analysis regardless of whether it is the subject's first or second exposure to the film task with no significant differences arising between test occasions for either the temporal ($F(1,3)=1.085, p>.05$) or the event ($F(1,3)=0.067, p>.05$) occlusion conditions. Test-retest correlations are substantially higher for the temporal occlusion trials ($r = 0.74$) than for the event occlusion trials ($r = 0.14$) although the magnitude of the correlation co-efficient in the latter case is undoubtably suppressed by the comparative similarity of the DT values across all of the event occlusion conditions.

Conclusions

The purpose of this experiment was to determine the extent of replicability in the visual search parameters used in Experiment 2. Although similar conclusions have been reached on each occasion the search parameters have been evaluated, adding to the confidence with which the conclusions proposed in Experiment 2 can be advanced, the extent of re-test reliability depends to a certain degree on the specific parameters used.

Fixation location characteristics appear to be highly replicable from one test occasion to the next and consequently the eye movement recording of subjects performing the film task is reliable in terms of the assessment it provides regarding the individual subject's cue usage.
and the individual subject's assignment of attentional priority to the available display cues. In a similar manner the search order appears consistent across the different testing occasions with the extent of intra-subject variability being quite small. Therefore in contrast to some reports from static picture viewing (e.g., Peterson, 1969; Yarbus, 1967) it appears that dynamic, time-constrained search tasks tend to substantially limit the search orders and regional priorities available to subjects, resulting in relatively high replicability for these aspects of the search process. Mean FD, as indicative of visual search rate, on the other hand, appears less replicable than the location and order parameters with the FDs apparently altering from trial to trial without exerting any observable effects upon task performance. Test-retest correlations for FD are relatively low (r ranged from 0.23 - 0.56 for the different occlusion conditions) and are markedly less than those reported by Iacono & Lykken (1981) over a two-year period for visual search of simple targets.

Although no prior literature on scan pattern replicability for applied visual search tasks is available the current findings are somewhat discrepant from the test-retest results reported by Buchsbaum, Pfefferbaum & Stillman (1972) over a two-week period for a simple size-estimation task. In contrast to the current findings Buchsbaum et. al. reported search rate, as estimated from the number of fixations, as the most reliable search parameter with a r of 0.82 and found fixation location to be relatively unreliable. Both studies are consistent in the conclusion of VCT (termed visual RT by Buchsbaum et al) as a parameter
which is unstable over time. Clearly the extent of individual search parameter reliability is dependent upon the task nature and undoubtedly features such as the ecological validity of the stimuli used, and the time constraints provided, influence the reliability obtained.

In conclusion, some aspects of the visual search analysis (viz fixation location and order) appear highly replicable and provide for a reliable assessment of an individual's perceptual strategies over time. Other aspects such as the search rate appear somewhat less stable for this particular task and caution is clearly needed in implying information-processing rate differences between individuals on the basis of this parameter. The visual search parameters show generally lower test-retest reliabilities than the comparable prediction error measures derived from the film task and this advantage, along with the more direct link to actual information extraction, suggests that, at this stage, greater weight should be placed upon the results of the film occlusion analyses than the visual search analyses in the assessment of individual perceptual strategies. Clearly, however, the advantages of using both film occlusion and eye movement recording procedures simultaneously outweigh the reliability and validity advantages of either of the procedures used in isolation.

III REPLICABILITY OF PARADIGM CONCLUSIONS UNDER CONDITIONS OF ALTERED SKILL GROUP DIFFERENTIATION AND RESPONSE MEASURE SELECTION

To date the major focus of this chapter has been upon the assessment of the validity and the reliability characteristics of the selected
paradigm and assessment of the replicability of the conclusions drawn in Chapter 5 has been restricted to test-retest manipulations. A further important question however, which has not been addressed, concerns the extent to which these same general conclusions regarding perceptual strategies in badminton, and especially the conclusions drawn regarding skill group differences in perceptual strategy, can be reached when a different skill group sample is used and a different response measure is computed. Examination of this question is important in order to overcome the possibility that the results obtained previously may have been an artifact of either the sample used or the response measure selected. Experiment 7 therefore sets out to examine the replicability of the previous results by presenting, to groups of subjects of less clearly differentiated skill level than those used in Experiments 1 and 2, the same film task as used previously but with altered response requirements.

EXPERIMENT 7

Method

Subjects Twelve experienced badminton players and 15 novice racquet sport players were selected as subjects. The experienced players were selected from the Sunshine Coast Badminton Association fixtures in Queensland, Australia and ranged in ability from regular A grade competitive level to National squad level. The ages of the experienced subjects ranged from 15 years to 40 years and the group consisted of four female and eight male players. The novice group was composed of undergraduates in Human Movement Studies at the University of Queensland and consisted of nine females and six males ranging in age from 17 to 26
years. Participation of all subjects was on a strictly voluntary basis and in this experiment, unlike Experiment 1, all subjects in each group were tested simultaneously rather than individually.

**Procedure** Subjects were shown the prepared film, as in the previous experiments and, for each film trial, were required to make a prediction of the stroke direction. Unlike the earlier experiments, however, no predictions of object depth were required. Subjects were required to rate the certainty of their directional predictions by, during the five second inter-trial interval, marking one of five possible Lickert-type responses viz, definitely cross-court (category 1), probably cross-court (category 2), uncertain (category 3), probably down-the-line (category 4) or definitely down-the-line (category 5). Instructions were given to subjects to utilize categories 2 and 4 if they had any notions as to probably stroke direction with the uncertain response to be only utilized under conditions where they genuinely considered both cross-court and down-line stroke types to be of equal probability.

The subjects' task therefore translates, in signal-detection terms, to one of determining whether each stroke that is presented originates from a distribution of cross-court strokes or a distribution of down-line strokes and then rating their judgmental certainty accordingly. The task and overall experimental design is therefore akin to that presented by Blignaut (1979b) in his examination of miners' ability to discriminate dangerous and safe rock formations. (More detailed considerations of the assumptions and relative strengths and weaknesses of this particular paradigm have been made in Chapter 4).
Analysis of Data  Both conventional error analyses and analyses of operator sensitivities within the signal-detection paradigm were calculated in order to determine the effect of response mode on the conclusions drawn.

(i) **Conventional Error Analyses**  Judgmental errors (i.e. assigning categories 3, 4 or 5 to actual cross-court stimuli or assigning categories 1, 2 or 3 to actual down-the-line stimuli) were summated for each occlusion condition for each subject and percentage error scores determined. These scores were then subjected to a 2-way (groups x occlusion conditions) analysis of variance for both temporal and event occlusion sections of the film test in order to derive results which could be compared directly with those obtained in Experiment 1.

(ii) **Response Sensitivity Analyses**  Three measures of sensitivity ($P(A), \Delta m$ and $d'_{e}$) were calculated with each aimed at comparing the discriminability of the cross-court strokes (arbitrarily designated as the signal distribution) from down-the-line strokes (arbitrarily designated as the noise distribution) for the different occlusion conditions (a within-group factor) and for the different levels of subject expertise (a between-group factor).

Given the original film design there were therefore 32 different trials presented in each occlusion condition composed of equal numbers of both cross-court and down-the-line strokes. Although forehand and backhand strokes were separated for the purpose of providing an alternative error term in later analyses of variance (see footnote 41) the effects of different stroke types within each occlusion condition
(e.g. forehands v backhands; smash shots v drop shots) was not a central concern in the determination of response sensitivities and therefore these effects were not subjected to any further separate analyses. The analyses of sensitivities performed generally followed the procedures described by McNichol (1972; chapter 5).

(a) **Determination of P(A)** For each subject for each of the 10 separate occlusion conditions the frequencies, probabilities and z-scores associated with correctly reporting a cross-court stroke as such (i.e. Σ(CC/cc), p(CC/cc) and z(CC/cc) respectively) and the equivalent error terms for labelling a down-the-line shot as cross-court (i.e. Σ(CC/dl), p(CC/dl) and z(CC/dl)) respectively) were determined using the procedures outlined in McNichol (pp. 105-108) and exemplified in Appendix D-1. The p(CC/cc) and associated p(CC/dl) values were then used to compute P(A)\(^{39}\) values for each cell through the use of the computer program 'pa.out' (see Appendix D-4) and mean P(A) values for skill groups and for occlusion conditions were then duly determined. In order to subject the sensitivity differences on these two factors to inferential analysis the P(A) values were then transformed to parametric equivalents using the \(\text{arcsin} \sqrt{P(A)}\) transformation\(^ {40}\) and analysis of variance was then conducted.

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39. P(A) is the area under the curve when P(S/s) is plotted as a function of P(S/n). P(A) approaches a value of 1 under conditions of maximum sensitivity when the respective signal and noise distributions are discriminated without error (see Appendix D-2 for an example from this experiment).
on the between-group factor of skill level and the within-group factor of occlusion conditions.

(b) Determination of $\Delta m$ and $d'_e$. The measures of $\Delta m$ and $d'_e$ were calculated as measures of discriminability to account for possible variance differences in the respective signal and noise distributions in the $P(A)$ measure (see Green & Swets, 1966, p. 96). The $z(\text{CC/cC})$ and $z(\text{CC/dd})$ values obtained previously for the different subjects were summated and used to determine group mean values (see McNichol, pp. 111-112 and the example in Appendix D-5) and these group mean values were then plotted on a double probability-scaled ROC curve (see McNichol, pp. 86-90 and the example in Appendix D-6). The respective $\Delta m$ and $d'_e$ measures of sensitivity were then derived for each group, as a function of the various occlusion conditions, and were used as a basis for qualitative comparison and as a supplement to the earlier $P(A)$ analysis. Unfortunately further inferential analysis of both these parameters could not be conducted because, for many of the subjects, a number of the

40. McNichol advocates the use of a $2 \arcsin \sqrt{P(A)}$ transformation but the method used here is a more conventional one. As the methods differ only in a constant however the same results from subsequent analysis of variance are achieved through either transformation.

41. In order to account for intra-subject variability on each of the occlusion conditions a third factor of stroke replications (i.e. whether the stroke was forehand or backhand) was also included in the analysis of variance. A conservative test of the critical groups x occlusion comparison was then gained by replacing the existing error term with the mean of the group x condition and the groups x conditions x replications error term so that each subject's performance variance on each occlusion condition became based on two observations rather than on a single observation.
Figure 162: Percentage errors in the prediction of shuttle landing position as a function of the degree of temporal occlusion for the expert and novice groups used in Experiment 7.

Significant differences exist between the groups at t2 only. For the expert group significant reductions in error occur from t1-t2, t2-t3 and from t3-t4 whereas for the novice group significant reductions occur from t2-t3 and from t3-t4.
individual cells contained only one set of usable z(CC/cc), z(CC/dl) coordinates (these were the cases where the subjects made the same response on every occasion the particular cross-court-down-the-line stimuli were presented), therefore making determination of the $\Delta m$ and $d_e$ values impossible.

Results and Discussion

(i) Response Error Analyses The percentage of lateral errors committed in this experiment by the two skill groups (see Figure 162) show remarkably similar trends across the different temporal occlusion conditions to those which were observed when two different skill groups were examined through the use of the absolute lateral error measure in Experiment 1 (cf Figure 25). A significant overall performance difference between expert and novice subjects is evident on the temporal occlusion conditions, in this case in favour of superior judgmental performance by the expert group ($F(1,25)=7.398, p<.05$), but the extent of the skill group differences is dependent upon what specific temporal occlusion condition is examined ($F(4,100)=3.548, p<.05$).

Superior performance by the expert group is evident at occlusion condition t2 (i.e. when information is occluded 2 frames prior to racquet-shuttle contact; $p<.05$) and, although both groups show greatest reductions in prediction error when information becomes available in the period from 2 frames prior to contact to 2 frames after contact, the distinguishing characteristic of the expert group appears to be their capacity to also use earlier information (available in the period from t1 - t2) to also reduce their prediction error ($p<.05$). In this comparable
Figure 163: Percentage errors in the prediction of shuttle landing position as a function of the event occlusion conditions for the expert and novice groups used in Experiment 7.

Experts differ significantly from the novices on all of the occlusion conditions.
time period novice subjects are unable to extract advance information which allows them to significantly reduce their uncertainty regarding stroke direction. These observed expertise-related differences in the time of critical information extraction parallel directly those findings regarding lateral error derived from Experiment 1. (See again Figure 25).

When the event occlusion conditions are considered (Figure 163) a significant overall difference is again evident between the performance of the expert and novice subjects ($F(1,25)=25.309, p>.05$) but on this occasion there is no significant group x occlusion interaction ($F(4,100)=0.959, p>.05$), indicating that the expert group performs with less prediction error on all five occlusion conditions. For both groups, conditions e1 and e2 (arm and racquet, and racquet alone) differ not only from all other conditions but also from each other ($F(4,100)=36.713, p<.05$) suggesting that useful advance directional information is being derived by both groups from both arm and racquet sources. This differs slightly from the earlier observations of absolute lateral error made in Experiment 1 (see Figure 34) where use of arm information was only evident for the expert group.

When event occlusion difference scores are computed (see Figure 164), and the effect of the differences in performance on the control

42. Whether or not e1 and e2 are concluded to differ and hence whether or not the arm is concluded to be a significant source of advance directional information depends on what post-hoc test procedure is adopted for both event occlusion analyses (Figures 163 and 164). If the Newman-Keuls method is adopted, as it has been throughout this thesis, the arm is concluded to be a significant source of information; if more conservative procedures such as the Scheffé or Tukey HSD tests are utilized the opposite conclusion is reached.
Figure 164: Increase in percentage errors in the prediction of shuttle landing position attributable to specific cue occlusion for the expert and novice groups used in Experiment 7. (Increases are expressed relative to the control condition eS).

No significant differences exist between groups although, for both groups, el differs significantly from e3 and e4.
condition are partialled out, no differences are then found to exist between the groups in terms of their cue usage either overall \( F(1, 25) = 0.679, p < .05 \) or for any of the four specific occlusion conditions \( F(3, 75) = 1.479, p < .05 \). A main effect for occlusion conditions is still evident however \( F(3, 75) = 38.091, p < .05 \) indicating, as previously, that, for both skill groups, both the arm and the racquet provide significantly greater information to aid stroke determination than do either the player's head or lower body \(^{42} \) (cf Figure 35).

In summary the percentage error analyses in this experiment reveal essentially the same overall conclusions regarding perceptual strategies in badminton as were derived from the lateral error analyses in Experiment 1. Specifically, the same conclusions are reached regarding greatest gains in directional information being in the period of about 170 msecs from 2 frames prior to racquet-shuttle contact to 2 frames subsequent to contact, and regarding the superiority of the racquet, and to a lesser extent the arm, as sources of advance directional information. The superior performance of expert players was again revealed to arise in the period from 4 frames to 2 frames prior to contact, as it was in Experiment 1, but slightly different conclusions were reached in this case regarding the sources of advance information for the two groups. Most evidently it was concluded in this experiment that novices, like experts, could utilize arm information to aid in early response selection, which was contrary to the earlier observations, although this conclusion was based on a borderline statistical decision (see footnote 42). Overall however, there was a high degree of similarity in the skill group differences in perceptual strategy evident
### TABLE 15

Mean values of the non-parametric measure of sensitivity P(A) for each of the temporal and event occlusion conditions for the expert and novice groups in Experiment 7

<table>
<thead>
<tr>
<th>TEMPORAL OCCLUSION CONDITIONS a</th>
<th>EXPERT GROUP</th>
<th>NOVICE GROUP</th>
</tr>
</thead>
<tbody>
<tr>
<td>t1</td>
<td>0.549</td>
<td>0.535</td>
</tr>
<tr>
<td>t2</td>
<td>0.699</td>
<td>0.556</td>
</tr>
<tr>
<td>t3</td>
<td>0.845</td>
<td>0.774</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EVENT OCCLUSION CONDITIONS</th>
<th>EXPERT GROUP</th>
<th>NOVICE GROUP</th>
</tr>
</thead>
<tbody>
<tr>
<td>e1</td>
<td>0.624</td>
<td>0.578</td>
</tr>
<tr>
<td>e2</td>
<td>0.702</td>
<td>0.561</td>
</tr>
<tr>
<td>e3</td>
<td>0.787</td>
<td>0.767</td>
</tr>
<tr>
<td>e4</td>
<td>0.855</td>
<td>0.762</td>
</tr>
<tr>
<td>e5</td>
<td>0.852</td>
<td>0.735</td>
</tr>
</tbody>
</table>

**Note:** The higher the value of P(A) the better the discriminability of the cross-court and down-the-line strokes.

a - P(A) values were not able to be computed for t4 and t5 because of the low error rates on these two conditions. Their true values approach 1.000.
in both this and the earlier experiment, indicating that the effects due to the subject's skill level are relatively robust ones. This would appear to be especially true when one considers the heterogeneity of the expert group used in this current experiment with large variabilities in both relative ability levels and years of playing experience evident within the group.

The form of error analysis used with this data set to date, however, essentially only mirrors the absolute lateral error analyses conducted in Experiment 1 and does not examine the robustness of the perceptual strategy conclusions across different response modes. To examine whether or not the same proficiency-related differences are apparent with an altered response mode it is necessary to examine the trends in the sensitivity measures derived from the signal-detection approach. The critical issue here therefore becomes whether or not expert subjects exhibit greater response discriminability than novices on the same specific occlusion conditions which distinguish them in the response error analyses.

(ii) Response Sensitivity Analyses Table 15 displays the P(A) values for the two skill groups for all occlusion conditions in which sufficient errors occurred for the statistic to be meaningfully calculated. In keeping with the observations made in other applied examinations of visual search and information extraction in both ergonomics (Blignaut, 1979b) and sport (Allard, Graham & Paarsalu, 1980; Allard &
Figure 165: Response sensitivity (arcsin $\sqrt{P(A)}$) in the prediction of shuttle direction as a function of the temporal occlusion conditions for the expert and novice groups used in Experiment 7.

Significant differences exist between the groups on condition t2. For the expert group significant increases occur from t1-t2 and from t2-t3 whereas for the novice group significant increases occur from t2-t3 only.
the highly skilled or experienced subjects were observed to have higher discriminability than the novices on all occlusion conditions. This indicates, in this case, a greater perceptual capability for the experts to discriminate strokes with a cross-court destination from strokes with a down-the-line destination on the basis of advance information alone. However in order to ascertain whether these observed differences are, in fact, due to the factor of sport-specific expertise and not merely a consequence of score variability it is necessary to examine the results of the analyses of variance performed on the transformed P(A) scores.

When the transformed sensitivity score is considered as a function of temporal occlusion (Figure 165), differences in discriminability between the skill groups are evident on some, but not all, occlusion conditions ($F(2,50)=3.332, p<.05$). Significant skill group differences are evident for the occlusion point two frames prior to contact ($p<.05$) but not for either the earlier ($t1$) or later ($t3$) occlusions. This appears to be a direct result of the expert group's unique ability to extract information in the period from $t1 - t2$ to significantly improve discriminability of the two stroke directions. Novices in the same time period cannot alter their response sensitivity.

These observations regarding the time periods for critical information extraction for the two groups mirror those obtained through

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43. All of the above cited studies using P(A) appear to subject this non-parametric measure directly, inappropriately, to analysis of variance rather than applying some form of intervening transformation to first normalize the data.
Figure 166: Response sensitivity ($d_{a'}$) in the prediction of shuttle direction as a function of the temporal occlusion conditions for the expert and novice groups used in Experiment 7.
Figure 167: Response sensitivity ($\Delta m$) in the prediction of shuttle direction as a function of the temporal occlusion conditions for the expert and novice groups used in Experiment 7.
Figure 168: Response sensitivity (arcsin $\sqrt{P(A)}$) in the prediction of shuttle direction as a function of the event occlusion conditions for the expert and novice groups used in Experiment 7.

Significant differences exist between the skill groups on all occlusion conditions.
the conventional error analysis (Figure 162) and parallel the conclusions reached in Experiment 1. Furthermore, these same conclusions seem warranted from the other derived measures of response discriminability as well (see Figures 166 and 167). In all cases it is evident that provision of visual information in the period immediately prior to contact facilitates the determination of stroke direction in a substantial manner and, further to this, vision of only small initial sections of shuttle outflight seems necessary in order to provide maximum resolution of directional uncertainty.

Analysis of the event occlusion task (Figure 168) reveals that a significant difference exists overall between the groups \( F(1,25)=15.976, p<.05 \) and between the occlusion conditions \( F(5,125=36.122, p<.05) \) but there is no interaction between the two factors \( F(5,125)=2.020, p>.05 \). For both groups masking of either the racquet and the supporting arm \((e1)\) or the racquet alone \((e2)\) produces lower discriminability of stroke direction than for any of the other conditions, and this is in keeping with the findings derived from the conventional error analysis (cf Figure 163). However, unlike the percentage error computation, the sensitivity for the occlusion of the racquet and supporting arm \((e1)\) does not differ, in this instance, from the condition in which the racquet only is occluded \((e2)\) suggesting that the supporting arm does not provide usable advance information for the determination of stroke direction.

Computation of event occlusion difference scores to partial out differences in the control condition performance of the two skill groups
Decrease in Response Sensitivity due to Cue Occlusion (arcsin $\sqrt{P(A)}$)

Figure 169: Decreases in response sensitivity (arcsin $\sqrt{P(A)}$) in the prediction of shuttle direction attributable to specific cue occlusion for the expert and novice groups used in Experiment 7. (Decreases are expressed relative to the control condition e5).

No significant differences exist between the skill groups.
Figure 170: Response sensitivity ($d_e'$) in the prediction of shuttle direction as a function of the event occlusion conditions for the expert and novice groups used in Experiment 7.
Figure 171: Decreases in response sensitivity ($d_e'$) in the prediction of shuttle direction attributable to specific cue occlusion for the expert and novice groups used in Experiment 7. (Decreases are expressed relative to the control condition $e_5$).
Figure 172: Response sensitivity ($\Delta m$) in the prediction of shuttle direction as a function of the event occlusion conditions for the expert and novice groups used in Experiment 7.
Figure 173: Decreases in response sensitivity ($\Delta m$) in the prediction of shuttle direction attributable to specific cue occlusion for the expert and novice groups used in Experiment 7. (Decreases are expressed relative to the control condition e5).
(Figure 169) indicates that both groups are similar in terms of their relative use of the different cue sources for information extraction; no differences are evident between the skill groups on the difference scores either overall ($F(1,125)=2.973,p>.05$) or on any of the occlusion conditions ($F(3,75)=2.135,p>.05$). For both groups occlusion of the racquet (either with the support arm or in isolation) causes a loss of direction discriminability which is greater than that encountered when either the player's head or lower body is occluded ($F(3,75)=29.132,p<.05$). The other measures of sensitivity or discriminability also heavily implicate the racquet as the principal source of advance information to aid in cross-court and down-the-line discriminations but there are again some discrepancies with respect to interpreting the associated importance of arm cues in the prediction process (see Figures 170-173).

Conclusions

Overall the analyses of response sensitivities in this experiment indicate a high degree of robustness in the conclusions reached to date regarding perceptual strategies in badminton. The findings emerging from this study, with altered skill group differentiation and response measure selection, are comparable to those obtained earlier in Experiment 1 (and then replicated in Experiment 5). Both data sets and both forms of response analysis indicate a reduction in lateral prediction error (and an increased discriminability of stroke direction) as more advance pre-flight information becomes available, with this reduction in uncertainty being most evident for both skill groups in the period from some 84 msec prior to racquet-shuttle contact to a further 84 msec subsequent to
This experiment, in keeping with the earlier ones, also reveals that
the greater capability of expert players to predict forthcoming stroke
direction is established in the time period beginning some 160-170 msec
prior to contact. Within this paradigm this indicates that experts not
only perceive the advance display in a superior fashion to novices but
are also more confident in making these perceptual judgments. As a
relationship appears to exist between perceived information probabilities
and commencement of anticipatory movement (Alain & Proteau, 1978), this
greater judgmental confidence for experts may well account for their
earlier response initiation in actual task settings (e.g. see Howarth et.
al., 1984).

In keeping with earlier analyses all three sensitivity measures
calculated in this experiment also identified the racquet region as the
single most important source of anticipatory information. There were
however, some discrepancies with respect to the importance of arm cues in
direction prediction both between the sensitivity measures and the
conventional error measures and within the three sensitivity measures
themselves. Overall however, the weight of the evidence provided in this
experiment lends considerable support to the confidence with which the
results and conclusions from Experiment 1 can be expected to be
replicated with different response modes and skill groups. In view of the
manipulations performed in this experiment, the evidence collected argues
strongly for the robustness of the proficiency-related differences in
perceptual strategy which have been observed earlier in this thesis.
IV CONCLUSIONS

A number of independent assessments of the validity, reliability and replicability of the paradigm selected for studying perceptual strategies in badminton (chapter 4) and the conclusions drawn from this paradigm (chapter 5), have been evaluated in this chapter. In terms of validity it has been demonstrated that the selected film test provides comparable attention demands to the field task of actually playing badminton and it has been demonstrated that the two data-extraction procedures of variable temporal and spatial occlusion and concurrent search pattern evaluation are independent. In terms of reliability it has been shown that identical conclusions are reached on the basis of prediction accuracy on each occasion the occlusion paradigm is implemented, although the concomitant visual search parameters seem subject to slightly greater test-retest variability. Finally, in terms of evaluating the replicability of the findings in a more global context, it has been demonstrated that essentially identical conclusions regarding the source of proficiency-related differences in perceptual strategy arise even when the response mode is altered from a continuous measure to one of rating judgmental certainty and even when less distinct novice-expert skill distinctions are drawn.

Although the paradigm has some obvious limitations in terms of simulating match conditions exactly (e.g. no sequential information is available to the subjects; only one opponent is used), its validity and reliability appears sufficiently well-established to support the majority of conclusions reached earlier regarding proficiency-related differences.
in perceptual strategy. Specifically, the available evidence provides support for the conclusion of a superior anticipatory capability for expert players, established in the time period some 170 to 80 msec prior to racquet-shuttle contact, and supports the implication that this is due, at least in part, to the ability of the expert player to extract advance information from not only the racquet but also from the earlier action of the arm.

Given that these replicable differences appear to exist between the perceptual strategies of expert and novice racquet sport players, a further question of critical interest becomes the nature of the development of these proficiency-related differences. Chapter 7 examines this question in more detail.
CHAPTER 7
THE DEVELOPMENT OF PERCEPTUAL STRATEGIES

In order to fully understand perceptual differences between experts and novices in sports skills, and to then further consider using these differences for higher order purposes such as skill development or talent identification, it is obviously crucial to have access to a strong data base regarding the developmental trends in critical perceptual variables (Abernethy & Russell, 1983; Régnier & Salmela, 1980b). In this chapter the existing data base for assessing developmental trends in both 'hardware' (optometric) and 'software' (processing) components of visual-perception is considered and an experiment is conducted to specifically examine the development of perceptual strategies in racquet sports.

'Hardware' Development

Unlike many other aspects of motor development relatively high degrees of visual-perceptual development are evident in even the very young child (Zaichowsky, Zaichowsky & Martinek, 1980, p. 72) with at least rudimentary acuity (Fantz, 1965) and depth perception (Bower, 1966; Gibson & Walk, 1960) functions being evident in infancy. Adult levels of static visual acuity are achieved by about age 10 (Lit, 1968; Weymouth, 1963) although maturation of control over dynamic eye movements may not be achieved until later in life. The parameter of dynamic visual acuity, for example, which is dependent upon accurate control over both smooth pursuit and saccadic eye movements, appears to continue improving in
efficiency through until the late teens (Abercrombie, 1969; Cratty, Apitzchi & Bergel, 1973) although again the most marked improvements in acuity are in the 8 - 12 years age range. There is conflicting evidence regarding whether or not peripheral visual performance is subject to developmental changes (e.g. compare the findings of Aspinall, 1976; Whiteside, 1976 and Osaka, 1980) although it appears that when a realistic control task demand is added, and divided processing attention is required, concurrent peripheral performance remains below adult levels at least until age 15 (Davids, 1983).

Although much of this "mechanical" development of the visual system is obviously completed relatively early (especially in terms of the career span of the sportsman/woman), much of the ongoing developmental variability in the visual-perceptual characteristics of the performer is contingent upon the way in which the performer chooses to utilize the available optometric 'hardware' at his/her disposal (Keogh, 1981, p. 216). For this reason examination of the developmental changes in perceptual variables which require active processing of information by the performer (i.e. 'software' variables) may be more enlightening than examination of purely 'hardware' variables.

'Software' Development

(1) The Development of Motion Prediction

One frequently utilized test of visual information-processing which is of relevance to the sports performer's ability to predict the motion of moving objects involves the determination of coincidence anticipation capability from apparatus such as the Bassin Anticipation Timer (after
Bassin, 1978). Generally the copious studies of the coincidence-anticipation performance of children and adolescents which are available have revealed a linear improvement in coincidence-timing performance with age (Alderson, Kenchington & Whiting, 1978; Bard, Fleury, Carrière & Bellec, 1981; Dorfman, 1977; Dunham, 1977; Haywood, 1977, 1980; Isaacs, 1983; Pavlis, 1972; Shea, Krampitz, Northam & Ashby, 1982; Stadulis, 1972b; Thomas, Gallagher & Purvis, 1981; Williams, 1969; Williams, 1982; Wrisberg & Mead, 1983). Adult levels of performance are usually reached on simple co-incidence-anticipation tasks by ages 11 - 13 (e.g. Alderson et. al., 1978; H.G. Williams, 1973) although this asymptote may be substantially later for more complex tasks (e.g. see Dorfman, 1977). The difficulty with accepting the findings of these studies as indicators of visual-perceptual capability for certain aspects of ball sport performance, on face value alone however, is that these studies utilize apparent and not real motion (see Pick & Pick, 1970) and are therefore subject to the same questions of ecological validity raised earlier in Chapter 3 (see pp. 93-94).

In field tests involving real object motion (primarily with catching tasks), age-related differences in visual information processing performance again became apparent (e.g. see Alderson, 1974; Bruce, 1967; McGrath, 1979; Williams, 1968). By ages 5 - 6 children appear capable of estimating ball trajectory with some accuracy but are unable to either anticipate the future coincidence point of the ball with the hand or plan their own response times (Kay, 1969). Thereafter the development of 'real world' motion prediction capability improves steadily, passing
through at least three intermediate developmental stages (for a description see Williams, 1973), before adult levels of achievement are attained at around ages 11 - 12 - i.e. at an age comparable to that estimated from the laboratory tasks. Parallel improvements in both simple reaction time and movement time (Carron & Bailey, 1973; Thomas et. al., 1981; Sugden, 1980) undoubtedly contribute to these observed improvements in motion prediction (Belisle, 1963), although clearly these latencies are far from being the sole determinants of coincidence-anticipation performance (Haywood, 1980).

Both the ability to extract object motion information (as estimated from coincidence-anticipation performance) and the control of the dynamic eye movements used in the extraction of this information therefore appear to be quite mature even by the time the performer reaches adolescence, yet peak performance in fast ball sports is usually reached at a much later age. Arguably it may be the later development of task-specific selective attention strategies (related to the ability to extract information from pre-flight rather than flight cues) which is responsible for this delayed attainment of peak competitive performance.

(ii) The Development of Selective Attention Strategies

Like the notions already advanced to explain differences between experienced and novice adult performers (see Chapter 3) the child is perhaps best considered in terms of being a '... less elegant information-processing system than the adult' (Wade, 1977, p. 379), limited primarily by the extent to which the available control processes can be mastered (Chi, 1976; Wickens, 1974). As the young performers
develop, their rate of information processing increases (Chi, 1977; Wickens, 1974) and this appears to be a direct result of their improved ability to selectively attend to important features of the display (see Hagen, 1967; Pick & Frankel, 1973) and to process task-relevant rather than task-irrelevant information (see Maccoby & Hagen, 1965; Smith, Kemler & Aronfreed, 1975; Stratton, 1978, 1979, 1980; Thomas, 1980; Vurpillot, 1968). As comparable amounts of visual (Sheingold, 1973), auditory (Siegel & Allik, 1973) and kinesthetic (Gallagher, 1980) information are briefly available to both children and adults through the respective sensory stores and as it appears that attention can only be re-located and not significantly increased or decreased (Simon, 1972, p. 15), the important development in the information processing capability of the child appears to be with the acquisition of appropriate strategies for attentional allocation.

Although young performers do not appear restricted in terms of access to a wide range of perceptual and task strategies (e.g. see the visual search strategy data presented by Cohen, 1981 or the data on movement coding presented by Gallagher, 1984), they seem to experience difficulty in selecting the most efficient or appropriate of the available information processing strategies and this leads to perceptual performance which is consistently below adult levels. Although the child may exhibit adult patterns of selective attention for simple tasks by around age 12 (Ross, 1976), for more complex perceptual tasks of the type encountered in fast ball sports this acquisition of an efficient perceptual strategy might be expected to occur at a much later stage in
the player's development.

(iii) The Development of Sport-Specific Anticipation

There is, unfortunately, a dearth of empirical evidence regarding the development of perceptual strategies in complex 'real-world' tasks of the type involved in making anticipatory predictions in racquet sports and this is particularly restrictive in view of the necessity for ecological validity within the research paradigm. The major reviews of motor development which are available (e.g. Connolly, 1977; Keogh, 1977, 1981; Thomas, 1980), although adopting information processing perspectives, fail to allude to any examinations of the development of perceptual strategies of the type required in sport and ergonomic settings. The existing laboratory studies are clearly quite removed from the 'real-world' setting and are therefore of limited value as recipient knowledge for the sport scientist (Davids, 1982). The existing laboratory studies are primarily concerned with young children who do not possess the concomitant effector skills to be involved in competitive fast ball sports, involve trivial tasks of reduced perceptual complexity, and frequently have a hardware (capacities) rather than a software (processing strategies) research orientation.

A very limited number of applied studies concerned with the development of perceptual strategies in sportspersons are available in the literature but these too have design problems which makes their direct application to the performance setting a difficult undertaking. Schubert (1981), for example, utilized a sequential reaction time task in which fencers of three different age groups (11/12; 13/14; 14/15 years)
were presented with a sequence of up to seven different stimulus lights (with each light given to simulate an element of the fencing action of an opponent). Subjects were required to anticipate the spatial location of the final light in the sequence, and Schubert concluded, on the basis of analyses of reaction times to the final light, that the ability to derive sequential information for anticipation increases systematically as the performers develop. The absence of ecologically valid stimuli and the absence of a control group of non-fencers for each of the age groups makes it extremely difficult however to extend these findings from beyond their laboratory context to make implications regarding the development of sport-specific knowledge of subjective probabilities.

In a similar vein to the work of Schubert, Haywood et al. (1981) examined the effect of contextual information (through manipulation of stimulus order) upon co-incidence anticipation performance and concluded, in that instance, that sequential information was not differentially detected by subjects from two different age groups (viz 8-9 year olds and adults). Once again the absence of ecological task validity and the selection, on that occasion, of a limited cross-section of age groups, each devoid of sport-specific expertise, limits the extent of 'real-world' knowledge of perceptual strategy development which can be generated from the study.

A more sport-specific test of perceptual performance was developed by Thiffault (1974) who utilized a procedure whereby subjects were shown a series of slides depicting tactical situations in ice-hockey and were required to make rapid response selection decisions on the basis of the
tachistoscopically displayed information. When the test was administered to five groups of ice-hockey players differing in both age and expertise (Thiffault, 1980) it was evident that the vocal reaction time measure allowed players from the Mosquitoe (age 8 – 10), Pee-Wee (age 11 – 12) and Bantam (age 13 – 14) Leagues to be differentiated with the vocal reaction times for the latter group being equal to those shown by an adult group (derived from University competition). Although this has been taken as evidence for improved perceptual performance being a function of task-specific experience (in this case ice-hockey experience) this effect is not definitively demonstrated in this study. Specifically in the absence of either a control group of non-players for each age group or control level vocal reaction times recorded under simple stimulus conditions it is impossible to determine whether the observed group differences are indeed a function of ice-hockey specific expertise or merely a consequence of age-related differences in general reaction time development which are 'hard-wired' into the system. Additionally the use of a tachistoscope for presentation of information which is normally of a dynamic nature and in which relevant stimuli normally arise from a wide range of locations with the visual field, raises again the consistent concern of ecological validity (see Davids, 1984, p. 36; Neisser, 1976). In this respect the tachistoscope may be particularly inappropriate when the testing of young subjects is involved (Hoving, Spencer, Robb & Schulte, 1978). A more recent application of slide presentation to simulate the visual display of the team game of 'Castleball' by Pauwels and Helsen (1984), which reached comparable conclusions regarding problem solving speed being a function of age, can
also be criticized along similar lines.

Souliere and Salmela (1982), in their study of anticipation in the sport of volleyball, utilized the temporal occlusion paradigm to compare the anticipatory performance of volleyballers of Senior, Junior and Recreational standard. Under the most difficult of the occlusion conditions (with occlusion approximately 170 msec prior to the attacker contacting the ball) Senior players predicted with greater accuracy (70% correct) the direction of the stroke than did either Junior (55% correct) or Recreational (36% correct) players and this was taken as evidence for the greater ability of experienced players to detect and utilize subtle postural cues available early in the event sequence. This study, however, like many of the other applied studies of perceptual strategy development (e.g. see Sinclair, 1980; Thiffault, 1980), appears to have confounded the skill level and age level effects by varying level of expertise through an age level manipulation. Consequently within these studies it is difficult to determine whether the altered anticipatory performance of the elite adult player is a consequence of their sport-specific expertise or a consequence of mere maturation. Evidence from other tasks has shown search rate to be dependent upon expertise but independent of age (e.g. the chess study by Charness, 1981), catching skills to be dependent upon age but not expertise (Starkes, 1981), and reaction time and eye movement parameters to be dependent upon both age and expertise (Yoshimoto et. al., 1982), highlighting the possibility that the effects of expertise and age upon perceptual strategy may be selective and therefore need to be examined independently.
Clearly a profound need exists for an empirical data-base on sport-specific perceptual strategy development which is based upon the use of controlled experimentation and in which age and proficiency related effects can be clearly differentiated. Experiment 8 was therefore designed and implemented in an attempt to determine the developmental trends in perceptual strategies for badminton and in an attempt to determine at what age the expertise-related differences in perceptual strategy observed for adults become established. Although a longitudinal study would have obviously been desirable the experiment performed was based rather on the comparison of the perceptual strategies of matched groups of experienced and novice badminton players of different age groups, with perceptual strategies assessed using the film occlusion paradigm established, validated and utilized in the previous chapters. The selection of the film occlusion paradigm allowed insight to be gained into the developmental trends, not only in anticipatory capability, but also in terms of the use of different anticipatory cue sources. It was predicted, in accordance with Maschette (1980), that there would be a progression in the capacity of subjects to extract information from advance cue sources with increasing age and skill development although no a priori notions were held regarding age related differences in spatial cue usage.

EXPERIMENT 8

Method

Subjects: Seventeen expert junior badminton players, who were Metropolitan representatives for their particular age grouping, were selected as subjects for the experiment. These seventeen players were
divided into three different age groups - a group of six of mean age 12 (consisting of four males and two females from an age range of 10 - 13 years), a group of seven of mean age 15 (consisting of five males and two females from an age range of 14 - 16 years) and a group of four of mean age 18 (consisting of four males from an age range of 17 - 19 years). Seventeen novice players selected from Physical Education classes in a Brisbane Metropolitan High School and matched in terms of age and sex to the subjects in the expert group were also used as subjects to form three corresponding novice groups of mean ages 12, 15 and 18 years respectively. Control groups of adult expert and novice badminton players were also incorporated by using the data set from the 20 experts and 35 novices collected in Experiment 1. Participation of all subjects was voluntary.

Procedures: All subjects were administered the film occlusion test as described in Experiment 1. Simultaneous testing of subjects occurred for both skill groups and on both test occasions experimentation was completed within 45 minutes. Concurrent eye movement recording was not undertaken, in contrast to the earlier adult experiment, primarily because of the unsuitability of the available eye movement recording device (i.e. the Polymetric Mobile V0165) for use with children (Young & Sheena, 1975a) and the observed lower reliability of the eye movement recording parameters (see Experiments 6 and 7). Individualized reports were given to the parents of subjects in the experiment and an example of an individual report is provided in Appendix E-2.

Analysis of Data: Data was analyzed using the procedures outlined
for Experiment 1. With the inclusion of adult data from that experiment the design became such that there were four principal independent variables of interest, i.e. the between group factors of age (4 levels) and expertise (2 levels) and the within group factors of occlusion type (2 levels) and occlusion condition (5 levels) with some 32 observations (4 replications of each of 8 stroke types) for each specific occlusion condition per subject. All dependent measures of prediction accuracy described in Experiment 1 were again computed using the program 'tennis out' (see Appendix B-3) but in this case attention was paid primarily to the radial error derivative. Analyses of variance and associated post-hoc tests of significance were computed using the same procedures as described for the earlier experiment.

Results and Discussion

(i) Temporal Occlusion Analyses

When the temporal occlusion conditions were compared using the radial error measure a significant interaction between the factors of age and expertise was evident ($F(3,81)=6.322, p<.05$) and this necessitated the independent consideration of the age effects for each of the skill groups. In the section which follows the age group effects are first considered separately for the two levels of proficiency and then the age x proficiency interaction is examined by comparing the expert and novice groups at each of the four age levels.

(a) Age Group Effects

Expert Subjects A significant age group effect exists for the
Figure 174: Radial error in the prediction of shuttle landing position as a function of the degree of temporal occlusion for the expert players in the four age groups in Experiment 8.
expert sample (see Figure 174) \((F(3,33)=7.627, p<.05)\) but the differences between the age groups is contingent upon the temporal occlusion condition being examined \((F(12,132)=2.096, p<.05)\). When the age groups are compared on each of the occlusion conditions some very clear evidence for improvements in anticipatory performance with age (and hence task-specific experience) emerges. All age groups display similarly high radial error on the earliest occlusion condition \((t1)\) but when advance information is provided up to the point 2 frames prior to racquet-shuttle contact the adult group is capable of reducing its prediction error to a point significantly different from all other age groups \((p<.05)\). When the occlusion point is further delayed to the point of racquet-shuttle contact \((t3)\) the adult group’s prediction performance remains superior to that of the 12 and 15 year old groups but is no longer superior to that of the 18 year old players. Finally when shuttle flight information is provided (in either the \(t4\) or \(t5\) conditions) the performance of the adult group again becomes superior to all other age groups, although no significant performance differences are evident between these other age groups.

A clearer indication of the developmental trends in anticipatory capability becomes evident however when the different age groups are compared across adjacent temporal occlusion conditions as in Table 16. It becomes evident in this table that the time period in which information becomes available which allows the players to significantly reduce their prediction error varies quite systematically according to the age of the players. Players in the 12 year old group are unable to
Comparison of radial error scores across adjacent temporal occlusion conditions for the expert players in the four age groups in Experiment 8

<table>
<thead>
<tr>
<th>TEMPORAL INCREMENTS</th>
<th>12 years</th>
<th>15 years</th>
<th>18 years</th>
<th>Adults</th>
</tr>
</thead>
<tbody>
<tr>
<td>t1 - t2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>*</td>
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<tr>
<td>t2 - t3</td>
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<tr>
<td>t3 - t4</td>
<td>-</td>
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<td>t4 - t5</td>
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</tbody>
</table>

* signifies a significant (p<0.05) decrease in radial error from the first occlusion time to the next on the basis of the Newman-Keuls post-hoc test.
TABLE 17

Comparison of radial error scores across adjacent temporal occlusion conditions for the novice players in the four age groups in Experiment 8

<table>
<thead>
<tr>
<th>TEMPORAL INCREMENTS</th>
<th>AGE GROUP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12 years</td>
</tr>
<tr>
<td>t1 - t2</td>
<td>-</td>
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<tr>
<td>t2 - t3</td>
<td>-</td>
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<tr>
<td>t3 - t4</td>
<td>-</td>
</tr>
<tr>
<td>t4 - t5</td>
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</tr>
</tbody>
</table>

* signifies a significant (p<0.05) decrease in radial error from the first occlusion time to the next on the basis of the Newman-Keuls post-hoc test.
improve their prediction accuracy significantly from any one temporal occlusion point to its successor, indicating that a relatively large span of extra temporal information needs to be provided to subjects at this age (such as the 170 msec of extra information in the time period from 2 frames before to 2 frames after contact; $p<0.05$) before they can resolve substantial uncertainty related to the stroke's landing position. On the other hand, 15 year old badminton players are able to improve their prediction accuracy significantly when shuttle flight information becomes available (i.e. in the time period from contact point ($t_3$) to 2 frames after contact ($t_4$)) whereas 18 year old experts are able to use late advance information (available in the period from $t_2 - t_3$) to bring about their first increments in task performance. Expert adult players, as has been seen earlier (Figure 24), are able to use even earlier advance information available in the period commencing 168 msec prior to contact (i.e. from $t_1 - t_2$), to significantly reduce their prediction error. The most outstanding feature of this data is then the observation that each increase in age for the expert subjects brings about an improved capability of the players to extract information from earlier and earlier events in the stroke sequence, thereby clearly supporting the notion (advanced by Maschette, 1980), of a progression to earlier cue extraction with task-specific practice.

**Novice Subjects.** Figure 175 presents the prediction performance of all four age groups of novice subjects compared across the five temporal occlusion conditions. Unlike the expert sample there were no significant main effects for age in the novice sample ($F(3, 48) = 0.910, p>0.05$) but there was evidence of some differences in the performance of the age groups on
Figure 175: Radial error in the prediction of the shuttle landing position as a function of the degree of temporal occlusion for the novice players in the four age groups in Experiment 8.
the different temporal occlusion conditions \( F(12,192)=2.475, p<.05 \). This age x occlusion interaction however was found to be due only to the superior performance of the 18 year old age group relative to the two younger age groups on condition t4 (i.e. the condition in which landing position prediction was required on the basis of information provided up to 84 msec subsequent to racquet-shuttle contact). Therefore, unlike the case for expert players, there is no apparent evidence to suggest that age exerts a systematic effect upon the anticipatory performance of the novice players and this suggests that task-specific experience (plus perhaps some initial innate anticipatory capability) are necessary in order to either produce good anticipatory performance or to develop anticipatory skills. Some differences within the prediction accuracy changes for successive temporal increments for the four age groups are evident (Table 17) but these effects are generally non-systematic. Improvements in prediction performance due to the successive availability of temporal information are very slight for the novice groups and there is nothing in the data set to suggest that age provides any systematic effect upon anticipatory performance as it clearly does for the expert group.

The comparison of the expert and novice data therefore supports the interpretation made earlier with respect to the information processing capability of children by Wickens (1974), that task-specific practice, and not maturation alone, is the principal avenue through which improvements in anticipatory ability take place. This is a conclusion which clearly could not have been reached through the use of experimental
Figure 176: Radial error in the prediction of shuttle landing position as a function of the degree of temporal occlusion for the expert and novice players in the 12 year old group in Experiment 8.

No significant differences exist between the groups. For both groups significant reductions in error occur from t2-t3 and from t3-t4.
Figure 177: Radial error in the prediction of shuttle landing position as a function of the degree of temporal occlusion for the expert and novice players in the 15 year old group in Experiment 8.

No significant differences exist between the groups. For both groups significant reductions in radial error occur from t2-t3 and from t3-t4.
designs such as those utilized in most of the earlier sport-specific studies.

(b) **Skill Level Effects**

**12 Year Old Subjects** When the anticipatory performance of the 12 year old subjects with expertise in badminton is compared with their novice counterparts (Figure 176), it becomes evident that the ability to predict the forthcoming stroke's landing position from advance cues does not differ between the two groups. No significant differences exist either between the skill groups overall ($F(1,10)=0.289, p>.05$) or on any of the five temporal occlusion conditions ($F(4,40)=0.719, p>.05$) suggesting that the superior anticipatory capability of expert adult badminton players emerges sometime after age 12 and that anticipatory capability plays a relatively minor role in badminton performance at this age.

For both experts and novices the presence of a significant main effect for occlusion conditions ($F(4,40)=46.591, p<.05$) indicates that prediction error is significantly reduced in the periods from $t_2$ - $t_3$ and from $t_3$ - $t_4$ but not in any of the other temporal increments.

**15 Year Old Subjects** The respective prediction errors under each of the temporal occlusion conditions for 15 year old subjects with and without badminton expertise are shown in Figure 177. As was the case with the 12 year old age group there are no significant skill group differences evident in the 15 year group either in terms of main effects ($F(1,12)=0.007, p>.05$) or interactions with occlusion conditions ($F(4,48)=1.802, p>.05$). Again, therefore, the weight of evidence indicates that playing performance differences between experts and
Figure 178: Radial error in the prediction of shuttle landing position as a function of the degree of temporal occlusion for the expert and novice players in the 18 years old group in Experiment 8.

Significant differences exist between the skill groups on t1 and t2. For the expert group significant reductions in error occur from t2-t3 and from t3-t4 whereas for the novice group significant changes occur from t3-t4.
novices at this age are not due to anticipatory differences but are more likely a function of other earlier maturing components of playing performance such as the effector skills of stroke production and control.

A significant main effect for occlusion conditions is evident, as it was in Figure 176, \((F(4,48)=22.863, p<.05)\) and once again this is due to significant increments in prediction accuracy arising from information available from 84 msec prior to contact (t2) to 84 msec after contact (t4), with no differences evident in the other time periods.

**18 Year Old Subjects.** Analysis of the data from the four experienced 18 year old badminton players and their novice counterparts (presented in Figure 178) again reveals no significant overall performance differences between the two skill groups \((F(1,6)=1.436, p>.05)\) although, surprisingly, significantly lower prediction errors are observed for the novice group on two of the 5 temporal occlusion conditions \((F(4,24)=3.163, p<.05)\). Specifically on the two most difficult temporal occlusion conditions (t1 and t2 where the display is occluded 168 and 84 msec respectively, prior to racquet-shuttle contact) lower radial error scores are returned by the novice group, although interestingly when either the Tukey or Scheffe post-hoc tests are administered rather than the Newman-Keuls approach a statistical conclusion of no differences between groups is reached. In view of the small sample size used for this particular age group \((n=8)\), the non-systematic direction of the differences observed (especially when compared with the adult data obtained from a much larger sample) and the dependence of the conclusion of selective group differences on the use of a liberal rather than conservative post-hoc test procedure, it would
appear logical to conclude that for this age group, like the younger ones, no systematic differences in anticipatory capability exist which can be attributed directly to the level of player expertise or task-specific experience. (It is worth noting that as no actual playing skill tests were administered it may be possible for subjects classified as novices on the criterion of non-regular badminton participation to be, in fact, quite competent racquet sport players. This may well be the case with the novice subjects in the 18 year old group whose performances throughout the occlusion tests consistently mirror those of an expert adult group rather than a novice group. See Figures 175 and 182).

**Adult Subjects.** The comparison of expert and novice adult badminton players on the temporal occlusion conditions has been provided in a prior analysis (see Figure 24). Both systematic main effects ($F(1,53)=36.271, p<.05$) and interactions with occlusion conditions ($F(4,212)=8.134, p<.05$) were found to exist for the skill groups with superior prediction accuracy being evident for the expert group on all temporal occlusion conditions except $t_1$, the very earliest occlusion condition. Most obviously the adult experts showed a capacity to use advance information available in the time period from 168 msec to 84 msec prior to contact (i.e. $t_1 - t_2$) to improve prediction accuracy - a capability which has not been shown in this experiment by any other skill or age group.

Given the assumption that all age groups used in this experiment have had skill group samples in which the expert and novice groups have been equally well discriminated, then it would appear reasonable to
conclude that the anticipatory skills of the expert badminton player only become developed relatively late in the maturation process, sometime after the late teens are reached. At all the pre-adult ages tested it appears that anticipatory capability is not a critical factor distinguishing the playing performance of the expert from the novice; rather, at these ages, other factors such as technique refinement, strength, agility etc., are probably more important in determining badminton performance level. On the basis of this data though it would appear that a need exists to integrate procedures for the development of anticipatory (and deception) skills into the training and coaching regimes for badminton players at an earlier age than occurs currently, as the necessary visual-perceptual hardware appears to exist well before any improved anticipatory performance becomes evident. The issue of training and coaching strategies for the development of anticipatory and perceptual strategies will be considered in more detail in Chapter 8.

(11) **Event Occlusion Analyses**

Having identified differences in the time at which critical information is extracted by players, which is both age- and expertise-contingent, an important subsequent issue becomes the isolation of the specific cues used by the respective age and skill groups in making their anticipatory judgments. This information was attained through consideration of the results of the analysis of the event occlusion conditions.
Radial Error (metres)

Figure 179: Radial error in the prediction of shuttle landing position as a function of event occlusion for the expert players in the four age groups.
Figure 180: Increases in radial error in the prediction of shuttle landing position attributable to specific cue occlusion for the expert players in the four age groups in Experiment 8. (Increases are expressed relative to the control condition e5).
(a) **Age Group Effects**

**Expert Subjects**  Figure 179 displays the radial error for each of the event occlusion conditions for all four age groups of expert players. Significant age ($F(3,33)=4.266, p<.05$) and event occlusion ($F(4,132)=59.619, p<.05$) main effects exist for this expert group, but there is no interaction between these two factors ($F(12,132)=1.722, p>.05$). For all the age groups examined occlusion of either the racquet plus the supporting arm (e1) or the racquet alone (e2) induces prediction error to increase beyond that of control conditions (e5). As both these occlusion conditions also differ significantly from each other ($p<.05$) the implication can be made that both the racquet and the arm provide critical sources of anticipatory information for all expert subjects, irrespective of their age.

The locus of the age group main effect cannot be isolated from the post-hoc procedures selected (the effects were tested using Scheffe, Tukey and Newman-Keuls procedures) but it would appear that across all 5 event occlusion conditions adults consistently produce less error than 18 year old players, who in turn produce less error than the 12 and 15 year olds.

When event occlusion difference scores are calculated (Figure 180), and differences between the age groups on the control condition (e5) are therefore negated, the only significant effect which remains is a significant main effect for the event occlusion conditions ($F(3,99)=62.342, p<.05$). Once again the same conclusions are reached with respect to cue usage, i.e. irrespective of the age of the subjects with
Figure 181: Radial error in the prediction of the shuttle landing position as a function of event occlusion for the novice players in the four age groups in Experiment 8.
Figure 182: Increases in radial error in the prediction of shuttle landing position attributable to specific cue occlusion for the novice players in the four age groups in Experiment 8. (Increases are expressed relative to the control condition e5).
badminton playing expertise, the critical cues used to extract task-relevant anticipatory information arise from the region of the arm and the racquet. As these perceptual strategy effects observed previously for expert adult players appear to exist across all age groups in the expert sample a fairly robust proficiency-related effect with respect to cue usage is apparent.

**Novice Subjects** The novice group's performance on the event occlusion conditions (see Figure 181) is not influenced by the age of the subjects ($F(3,48)=0.733, p>.05$) but only by the specific event occlusion conditions used ($F(4,192)=30.075, p<.05$). Post-hoc analysis reveals that, irrespective of the age of the novice subjects, conditions e1 (arm and racquet occluded) and e2 (racquet only occluded) produce the greatest radial error, differing significantly from all other conditions but not from each other. Consequently the novice players (irrespective of their age) extract all their relevant anticipatory information from the racquet alone and do not use the additional information available from the arm, as do expert players of all ages. These effects are more clearly illustrated when the increases in radial error attributable to specific cue occlusions are plotted (Figure 182) and again, in this case, identical statistical conclusions are reached regarding the novice player's dependency on the different available cue sources.

Stark contrasts therefore exist with respect to the anticipatory cue usage of the two skill groups, and these differences in perceptual strategy appear to be particularly robust ones holding across all four age groups investigated in this experiment. In view of the equality of
Figure 183: Radial error in the prediction of shuttle landing position as a function of event occlusion for the expert and novice players in the 12 year old group in Experiment 8.

No significant differences exist between the two skill groups.
the anticipatory performance of the expert and novice players up to age 18 (observed in the earlier temporal occlusion analyses; Figures 176-178).

It would appear that the advantage of using a 'racquet + arm' strategy to improve anticipatory performance takes some considerable time to emerge. Only at the adult level does this particular strategy appear to allow the expert players to improve their anticipatory performance beyond that of the matched novice player. This is not to say, however, that information arising from the arm action cannot be used meaningfully at an early age - to the contrary the expert players show an ability to extract task relevant information from the arm as early as age 12. Rather this use of the arm appears to be made at the expense of some concurrent racquet-based information. In order to determine whether the division of attention between the arm and the racquet by the expert players might perhaps be causing some reduced information extraction from the racquet alone the comparison of the cue usage of the two skill groups across the different age categories may be enlightening.

(b) **Skill Level Effects**

**12 Year Old Subjects** By age 12 there are no significant differences either overall for proficiency \((F(1,10)=0.000, p>.05)\) or between skill groups on the different occlusion conditions \((F(4,40)=0.511, p>.05)\) (see Figure 183). A main effect for occlusion conditions is evident \((F(4,40)=9.344, p<.05)\) which indicates that, for both skill groups, \(e1\) (arm plus racquet occlusion) produces significantly greater error than all other conditions, including \(e2\) (racquet only occlusion). Surprisingly for this comparison the occlusion of the racquet alone (\(e2\)
Figure 184: Increases in radial error in the prediction of shuttle landing position attributable to specific cue occlusion for the expert and novice players in the 12 year old group in Experiment 8. (Increases are expressed relative to the control condition e5).

No significant differences exist between the two skill groups.
Figure 185: Radial error in the prediction of shuttle landing position as a function of event occlusion for the expert and novice players in the 15 year old group in Experiment 8.

No significant differences exist between the two skill groups.
Figure 186: Increases in radial error in the prediction of shuttle landing position attributable to specific cue occlusion for the expert and novice players in the 15 year old group in Experiment 8.

No significant differences exist between the two skill groups.
does not induce significantly greater prediction error than for any of
the other conditions, implicating the arm alone as the principal cue
source for 12 year olds.

When event occlusion difference scores are considered (Figure 184)
similar conclusions are reached. Specifically, the only significant
effect is a main effect for occlusion conditions ($F(3,30)=14.208, p<.05$)
which is attributable to the greater error induced by racquet and arm
occlusion than by any other condition. Although the event occlusion
difference score plots indicate the same conclusions reached earlier
(Figure 180) regarding greater use of arm information by experts, these
effects do not reach significance levels for the 12 years group.

15 Year Old Subjects At the 15 year age level (see Figure 185)
there are also no significant proficiency level ($F(1,12)=0.238, p>.05$)
or proficiency x occlusion condition interaction effects
($F(4,48)=1.113, p>.05$). As with the younger age group there exists a main
effect for event occlusion conditions ($F(4,48)=8.320, p<.05$) but in this
age group it is attributable to the significant differences between $e_1$
and $e_2$ and all other conditions. As $e_1$ and $e_2$ are themselves not
different the principal source of anticipatory information at this age
would appear to be the racquet.

The event occlusion difference score analysis (Figure 186) leads to
the same conclusion as observed for the absolute scores; the only
significant effect being a main effect for occlusion conditions
($F(3,36)=8.552, p<.05$) attributable to the equal importance of the arm
plus racquet ($e_1$) and the racquet only ($e_2$) in advance information
Figure 187: Radial error in the prediction of shuttle landing position as a function of event occlusion for the expert and novice players in the 18 year old group in Experiment 8.

No significant differences exist between the two skill groups.
Figure 188: Increases in radial error in the prediction of shuttle landing position attributable to specific cue occlusion for the expert and novice players in the 18 year old group in Experiment 8. (Increases are expressed relative to the control condition e5).

No significant differences exist between the two skill groups.
extraction. Once again the event occlusion difference plots support the contention regarding greater use of arm information by the experts but, as was the case with the 12 year old group, statistical significance was not achieved in terms of a proficiency x event occlusion interaction ($F(3,36)=0.600, p>.05$).

**18 Year Old Subjects** When the differences in radial error between expert and novice 18 year old subjects on the event occlusion conditions are examined (Figure 187) significant main effects for occlusion conditions exist ($F(4,24)=8.148, p<.05$) but, again, in the absence of significant proficiency ($F(1,6)=0.418, p>.05$) or proficiency x occlusion condition ($F(4,24)=0.899, p>.05$) effects. As was the case with the 15 year old group, this occlusion main effect is due to the greater error associated with conditions e1 and e2 than all other conditions and, in the absence of significant e1 - e2 differences ($p>.05$), the racquet is again implicated as the principal source of anticipatory information. This conclusion is supported by the event occlusion difference analysis (see Figure 188) with a main effect for occlusion conditions ($F(3,18)=6.971, p<.05$) existing which is again attributable to the criticality of the prediction information provided by the racquet. The trend for greater use of the arm information by experts observed for the other age groups is again in evidence but with this age group the effect is not sufficiently strong (due to the small sample size) to reach statistical significance ($F(3,18)=1.134, p>.05$).

Therefore for all three independent age group analyses the visible differences in cue usage between experts and novices in terms of the
expert's greater reliance on arm information have failed to reach acceptable significance levels. However, as has been observed earlier, when this independent age group data is combined with the adult data, in which significant differences between the groups in cue usage are evident (see Figures 32 and 33), overall differences in cue usage between experts and novices emerge, which are independent of the age of the subject. Consequently it would appear that the failure to replicate the differences in arm information usage when the age groups are considered separately may be a result of the small sample sizes used rather than being a contradiction to the existence of proficiency-related differences in perceptual strategy.

Overall it appears therefore that differences in perceptual strategy emerge reasonably spontaneously as a consequence of sport-specific experience. These strategies of reliance upon arm cues in addition to racquet information which are evident even by age 12 for expert badminton players may be a function of imposed strategies learned from coaches and other players or may be a preferred mode of processing which is essentially forced upon the player by the temporal constraints of the actual playing situation. It does, however, apparently take some degree of maturity (or extended task-specific practice) before this strategy of extracting information from both the arm and the racquet actually facilitates anticipatory performance (the anticipatory performance of the expert players is only superior to novices at adult age). The expert player's ability to use advance arm cues for stroke prediction may only become advantageous when the speed of the game becomes such that racquet
head information arrives too late to effectively aid response selection. Such temporal constraints may only be evident at elite adult age competition.

In terms of some of the developmental notions regarding selective attention presented previously (e.g. Maccoby & Hagen, 1965; Stratton, 1980) it should also be noted that for all the age x proficiency level comparisons based on absolute event occlusion scores there is no evidence of prediction error differences between the control conditions in which either irrelevant event occlusions (e5) or no event occlusions (t3) are provided ($F(3,81)=0.699, p>.05$). This indicates an absence of distraction by task-irrelevant information for any of the age or skill groups investigated and indicates that the selective attention functions which distinguish the expert from the novice in applied situations, such as this, are somewhat different from the kind of selective attention functions which have been examined in the developmental literature. The expert and novice badminton player are clearly not discriminated on the extent to which they are distracted by task-irrelevant information but are rather discriminated by the types of strategies they use in the extraction of situation-specific task-relevant information.

**Conclusions**

The following conclusions seem justified on the basis of the evidence accumulated from this experiment.

1. This experiment, unlike previous investigations of the development of anticipatory skill, appears to have been able to differentiate
the effects of maturation and task-specific practice through the
use of expert badminton groups of different age and the formation
of matched age groups of novice players. Results indicate that
the ability to anticipate the landing position of a forthcoming
stroke in badminton does not improve through general maturation
alone but that rather task-specific experience is necessary in
order to increase the capability to extract information from
advance cues. Over each developmental period examined there is a
progression to earlier information extraction for expert players
(in keeping with the predictions of Maschette, 1980) but it is
only at the adult level that this cumulative task-specific
experience allows the anticipatory performance of the expert
players to significantly exceed that of their novice counterparts.
This relatively late development of anticipatory superiority for
expert badminton players suggests that, at least currently,
anticipatory capability is not a critical factor distinguishing
the expert junior player from the lesser skilled (arguably other
factors such as stroke production, agility etc. account for more
performance variance at the pre-adult level) and supports the
earlier contention that the visual perceptual superiority of the
elite adult performer is more a 'software' function than one
related to the developing optometric 'hardware'. Development of
anticipatory and decision making skills evidently occurs well
after optometric parameters, such as visual acuity measures and
simple response speed parameters, such as reaction time and
movement time, have reached adult levels (cf Konzag, 1983).
From the very earliest age group examined expert and novice badminton players appear to utilize fundamentally different perceptual strategies in order to extract advance information to aid stroke prediction. Across the different age groups experts appear to extract critical information from both the racquet and the arm holding the racquet, whereas novices use racquet information alone, possibly indicating that these characteristic perceptual strategies which emerge for expert players are either the result of strategic instruction provided through standardized coaching or arise spontaneously in response to the temporal constraints imposed by actual playing conditions. It does, however, take some time for this 'arm + racquet' strategy to become advantageous for anticipatory performance (emerging as a superior strategy at the adult level only) and this may possibly be because of the initial difficulty, which may be experienced by younger players, in dividing focal attention between these two distinct regions of the display.
CHAPTER 8

SUMMARY, CONCLUSIONS AND FUTURE DIRECTIONS

A/ Summary

This thesis has been concerned with the determination of the critical visual-perceptual factors which discriminate the expert racquet sport player from the novice. The contemporary perspective of the human performer as an information-processing-like system has been adopted and perceptual performance has been seen throughout to be limited by both the physical constraints of the available visual-perceptual apparatus (i.e. 'hardware' limitations) and the performer's ability to use this 'hardware' to maximal efficiency (i.e. 'software' constraints).

The excessive time constraints placed upon information processing in fast ball sports have been shown to result in the availability to performers of only very limited viewing times in which to perform the precise perceptual analysis of the display which is necessary for successful performance. As these stringent time constraints obviously necessitate efficient use of selective attention processes it was predicted in Chapter 2 that task performance in racquet sports might be closely related to how effectively the performers could utilize this available time.

The perceptual strategies used in time-constrained situations like fast ball sports, it was noted, appear to reflect the pertinence assigned to different features of the environmental display by individual performers (Norman, 1969) with this assignment involving the matching of
current sensory information with contextual and expectational information arising from prior task-specific experience. These multiple inputs to the selective attention process provide a number of avenues for individual and group differences in perceptual performance to occur. Consequently some of these possible differences in the perceptual (selective attention) strategies of expert and novice performers were advanced for study in Chapter 3. The hypothesized differences were in terms of both the quantity of input information to be processed and the quality of the to-be-processed input (as assessed from different assignments of pertinence) and some evidence was found in the extant literature to support both these contentions.

A growing body of both laboratory and field evidence was found specifically pointing to the greater ability of expert performers in fast ball sports to utilize advance information. This ability of the experts to extract early information was seen to have the effect of increasing the redundancy associated with many subsequent events (such as ball flight) and had the effect of decreasing the quantity of information to be processed. Much of the superiority of the expert performer for recognizing situational redundancy appeared to be attributable to the expert's greater knowledge of situation structure (i.e. a 'software' difference) rather than to any measurable differences in the mechanics of the visual system (i.e. 'hardware' differences; Starkes & Deakin, 1984). Some evidence of qualitative differences in the location of specific cues used for the extraction of response selection information was also
found in the existing sport science literature. It appeared that in some instances experts and novices faced with the same display gave priority to different sections of the display either on the basis of their different prior knowledge of the potential location of useful cues or on the basis of differences in the subjective probabilities assigned to different potential response outcomes (e.g. Alain & Proteau, 1977, 1980; Schubert, 1981; Whiting, 1979). When visual search patterns were recorded from displays simulating those of specific sports (e.g. Bard & Fleury, 1976a, 1981; Bard et. al., 1980, 1981; Haase & Mayer, 1978; Ripoll et. al., 1982, 1983) differences in the percentage numbers of fixations given to different cue sources were evident, supporting directly the notions of skill-group differences in pertinence assignment. Moreover within these few studies of sport-specific visual search some differences in visual search rate were also reported in the direction of lower search rates (and therefore longer mean fixation durations) for experts. This was interpreted to be a consequence of the reduced total amount of information that experts were forced to process because of their a priori awareness of the location of critical information within the display.

The existing sport-specific research which addresses these issues of applied selective attention and proficiency-related perceptual strategies was unfortunately found to be riddled with methodological and design flaws, not the least of which related to the question of ecological validity. For this reason it was concluded from the review of literature in Chapter 3, that advancement of understanding of perceptual strategies in sport appears to be primarily limited by the absence of an
ecologically valid test of perceptual strategy of proven validity and reliability. The first stage of this thesis was then an attempt to rectify this problem.

After a consideration of a number of potential paradigms and their respective assumptions, limitations and weaknesses (Chapter 4), it was decided to examine cue usage through the implementation of a multi-procedural paradigm involving the concurrent use of both film occlusion and eye movement recording. The film occlusion technique was extended beyond prior applications (e.g. see Jones & Miles, 1978; Salmela & Fiorito, 1979) to include not only a temporal occlusion condition, in which the time at which the display was occluded was varied, but also an event occlusion condition, in which the effect on anticipatory performance of selective occlusion of specific cue sources was determined. This use of simultaneous data-extraction systems was seen as logical in terms of the necessity for sport-specific focus, ecological validity, individual differences analyses and multiple levels of analysis within the research paradigm (Salmela, Partington & Orlick, 1982). The paradigm finally selected provided an avenue for examining hypotheses related to differences in perceptual strategy based on the quantity, quality, and rate of information to be processed and was seen as a potential means of discriminating the timing and location of critical information extraction for racquet sport players of different levels of expertise.

An attempt was then made, through a series of experiments performed in Chapter 6, to ensure that this selected procedure provided both
acceptable validity and reliability for the assessment of individual
differences in perceptual strategy. It was revealed, in terms of
validity, that the selected film task placed demands on the subjects
comparable to the actual playing situation (Experiment 3) and that data
could be recorded concurrently and independently from both the film
occlusion tests and the eye movement recording apparatus without
interference between the two data-extraction systems (Experiment 4).
Further, the dependent measures of prediction error calculated from the
film occlusion task were found to have high reliability, with identical
conclusions being reached regarding perceptual strategies, both in terms
of the timing and location of critical cues, on each occasion the test
was administered (Experiment 5). Visual search parameters were shown to
be somewhat less reliable than the parallel prediction errors, with the
same prediction performance being apparently possible from different
fixation rates. The search order and distribution of fixations across
the display were however reasonably consistent from one occasion to the
next.

The procedures designed in Chapter 4 for examining the time and
location of critical cue usage, and shown later to be both valid and
reliable (Chapter 6), were used in two experiments in Chapter 5 to
examine hypotheses related to differences in perceptual strategy between
expert and novices.

In keeping with earlier studies in fast ball sports (e.g. Abernethy
& Russell, 1984; Jones & Miles, 1978; Patrick & Spurgeon, 1978; Soulière
& Salmela, 1982) it was shown that expert racquet sport players were
indeed more aware of redundancies existing within the perceptual display presented by an opponent, and were indeed more capable of extracting information from early advance cues, than were novices. Experts were shown to be capable of reducing their prediction error at an earlier time period than could novices (experts first reduce their prediction error in the period from around 170 msec to around 85 msec prior to racquet-shuttle contact whereas novices do not significantly decrease prediction error until some 85 msec later) suggesting that the experts were able to extract information from earlier occurring cue sources. These cue sources were apparently not recognized as informative by the novices. This effect of earlier information extraction by proficient badminton players was later shown to be a robust one, remaining even when different skill group samples were examined and when the response mode was altered to facilitate a signal-detection analysis of response sensitivity (Experiment 7).

In response to a second hypothesis derived from selective attention notions regarding differences in the assignment of pertinence to different cue sources, it was observed that while both experts and novices use information from the racquet as the principal source of task-relevant anticipatory information, the experts additionally use information arising from the spatial location of the arm to facilitate anticipatory performance. As the availability of information from the arm undoubtedly precedes the availability of racquet head information (due to the proximal-to-distal development of the badminton stroke kinematics) it appeared feasible to conclude that the ability to extract advance information from arm cues may have been a principal factor
underlying the superior ability of the expert players to extract early information from the display.

The corresponding eye movement recording analyses were unable to discriminate the skill groups on any of the visual search parameters, illustrating the potential problems associated with using measures of visual orientation alone without concomitant measures of actual information-extraction. For both groups the racquet head area was most frequently foveated with the search sequence, irrespective of the subject's expertise, occurring in a primarily proximal-to-distal manner matching the emergent stroke characteristics. Contrary to some earlier sport-specific visual search studies (e.g. Bard & Fleury, 1976a; Bard et. al., 1980) no significant differences in fixation durations were evident between the two skill groups indicating that all subjects, again irrespective of their badminton playing expertise, tended to search the perceptual display of their opponent at approximately equal rates. This finding therefore cast doubt upon fixation duration as a good indicator of relative information-processing demands.

Some additional findings and implications emerged from Experiments 1 and 2 (Chapter 5) related to the role of different cue sources in the differentiation of stroke depth and direction and the effect of different stroke types upon the perceptual performance of the two skill groups. The determination of stroke direction (as assessed from lateral prediction error) was found to be quite cue-specific with information from the racquet region (for both skill groups) and from the supporting arm (for expert players) being critical in this regard. The
determination of stroke force, and hence the landing depth of the stroke, was found to be less cue-specific, with information from quite large and diverse sections of the display apparently contributing to stroke depth judgments. This differentiation of cue involvement in stroke prediction on the basis of directional or depth contribution was found to be compatible with many of the predictions from contemporary two-mode theories of visual perception (e.g. Held, 1970; Ingle, 1967, 1975; Ingle et. al., 1967; Leibowitz & Post, 1982; Schneider, 1969; Trevarthen, 1968). The determination of stroke direction was hypothesized as occurring mainly focally through the use of foveation upon the racquet at contact, and, to a lesser extent, the arm prior to contact. This focus was necessary in order to accurately derive information of predictive value regarding the angle of the racquet head at the point of contact. The determination of stroke force, on the other hand, was seen to require a perception of the relative speeds of both the racquet and the 'whole' player up to the point of contact and information of this type is known to be best derived through the use of both foveal and peripheral vision acting together in an 'unfocussed' manner (see Dichgans & Brandt, 1978; Paillard, 1980).

Although overall the expertise-related differences in perceptual strategy were found to persist over all stroke types examined in Experiments 5 and 6, some specific differences in perceptibility for different stroke types were discovered. Both skill groups found backhand strokes more difficult to anticipate than forehand strokes and this was apparently due to the unavailability of a few specific cue sources for
the backhand strokes which provided reliable anticipatory information for the forehands. Expert players were found to be equally proficient at predicting strokes with cross-court and down-the-line destinations whereas novice players experienced greater difficulty with the anticipation of cross-court strokes. The novice's failure to predict cross-court stroke direction at an early stage in the stroke sequence was attributed to their failure to utilize arm cues which provide an early indication of the alteration from the open racquet head position used at contact for down-the-line strokes to the closed contact position necessary for cross-court strokes. As was the case with strokes of different direction the expert players were found to predict strokes of different depth (smash strokes and drop-shots) equally well whereas novices experienced greater difficulty with the advance prediction of the landing position of drop shots. Failure to derive information from early arm cues and a lack of situation-specific familiarity with shuttle flight characteristics were seen as the contributing factors.

In view of the robust nature of the observed differences between expert and novice adult badminton players both in terms of the time at which useful anticipatory information becomes available to them and the location of the cues they use to make anticipatory judgments, an important issue became the manner in which these perceptual strategy differences were developed. When the temporal and event occlusion performances of expert and novice badminton players of different age groups were compared (Experiment 8) it became apparent that task-specific experience, rather than the effects of maturation alone, was the principal agent behind the development of perceptual expertise. Expert
subjects, unlike novices, showed progression to earlier information extraction at each of the four age increments examined (i.e., 12, 15, 18 and adult ages), although it was only at the adult level that anticipatory performance appeared to become a reliable factor discriminating the playing performance of the expert from that of the novice. Throughout all age levels expert subjects showed the persistence of a characteristic 'arm + racquet' strategy for advance information extraction in contrast to a characteristic 'racquet only' information-extraction strategy for novices. This suggested that these differences in cue usage may emerge either as a consequence of imposed coaching strategies or as a result of experiencing directly the temporal constraints of decision-making within the actual playing environment.

B/ Implications

Overall then a number of systematic differences in perceptual strategy between experts and novices have become evident in this thesis. Most notably expert racquet sport players have been shown to be capable of extracting earlier information regarding the landing position of the forthcoming stroke (as well as being capable of maintaining more accurate predictions at later occlusion points) and appear capable of utilizing the arm, in addition to the movement of the opponent's racquet, as a source of task-relevant anticipatory information. In view of this knowledge, and in view of the ability of the occlusion procedures to clearly discriminate expert and novice performers, there is an obvious need to develop and implement training procedures which are capable of enhancing the anticipatory capabilities, and hence the playing potential,
of any individual player. However, despite its apparent importance perceptual training is as yet a largely neglected aspect of most modern skill development programs for fast ball sports (Arend, 1980) and so clearly a necessity for systematic training procedures to enhance anticipatory skill development is strongly and urgently implicated (e.g. see Abernethy & Russell, 1983; Maschette, 1980).

A number of practical approaches for enhancing anticipatory skill development appear possible. Careful observation and analysis of the movement patterns and play strategies of opponents viewed under match conditions is an increasingly common component of modern coaching strategy (particularly since the universal availability of the video recorder), and this would appear to potentially provide a sound basis for the development of selective attention processes through enhanced advance knowledge of event probabilities. Although vision of an opponent from a perspective external to the actual game setting may provide a sound basis for accurate simulation of the opponent's display during training (Lawther, 1972, pp. 116-117) and this close simulation is obviously important for maximizing transfer from the training setting to the real setting (Stammers & Patrick, 1975), limitations in ecological validity arise through difficulties in accurately replicating the perceptual display of the opponent from the required 'in-game' perspective.

In order to overcome this 'external' perspective problem a number of researchers have attempted to improve anticipatory performance through the use of training films which present display information from the performer's perspective i.e. film displays of the same kind used to
present the temporal occlusion trials in the experiments reported in this thesis. Haskins (1965), Jones (1974) and Day (1980) with tennis players, Thiffault (1974) with ice-hockey players, Burroughs (1984) with baseball batters and Bilgnaut (1979a) with mine workers, have all reported improved anticipatory and general visual search performers as a consequence of repeated exposure to film-presented display information and accompanying performance feedback. Unfortunately these studies, in the main, only demonstrate improved film task performance as a consequence of the film training and parallel improvements in 'on-site' performance are often not forthcoming (see especially Day, 1980), suggesting that the locus of improvement may be with film familiarity rather than facilitated 'real-world' anticipatory skill. These improvements in film performance are probably to be expected when one considers the relatively small numbers of film trials often used in the initial assessment of anticipatory capability.

Another problem which has limited the applicability of training films to date has been the apparent absence of any clear directions to the subjects as to how to improve their anticipatory performance while viewing the film simulations. In this respect both researchers and coaches have been limited to date by the absence of a sound knowledge base regarding either the location of critical cues or the differences in cue dependence between experts and learners (Sharp, 1973, p. 397) and this has restricted users of the training films to dependence on passive and incidental forms of learning. No empirically-based guidelines have been available to allow the coach to dynamically direct and influence the learning of selective attention strategies.
Perceptual training for novice performers may be inappropriate in many cases because anticipatory skills may only set the limits to performance at a stage well after the associated motor skills have been learnt and refined (Haskins, 1965). In the early stages learners will be incapable of receiving the same sensory information for selective attention as experts because they are incapable of producing the same kind of efficient motor responses as experts (Annett & Kay, 1956). The use of the film task itself, in isolation from the developing motor responses, may be an inappropriate form of preparation for sport-specific perceptual expertise as the visual and motor activities in sport skills may be inextricably linked (Lee, 1980).

An alternative approach to enhancing the development of anticipatory skills, which can retain the actual performance context and the concomitant motor activity, involves intensifying the relevant anticipatory cues, through the use of procedures such as colour coding (see Maschette, 1980), often in conjunction with psychological intervention in the form of focussing strategies (e.g. Brown & Mahoney, 1984; Nideffer, 1981, pp. 196-201). However, despite the presence of substantial literature supporting the concept of learning through selective attention to a limited range of relevant cues only (e.g. Gentile, 1972), attempts to enhance the rate of skill acquisition through intensifying the regulatory visual cues have been generally unsuccessful. Berlin & Linder (1971) report on the research of Bush (1961), Frazier (1952), Linder (1969) and Walters (1952), all of whom have failed to demonstrate any differences between skill acquisition under conditions where certain cues are intensified and skill acquisition under conditions
where conventional teaching-learning strategies are adopted. Again, as was the case with the training films approach, the absence of a sound basis for deciding what cues are indeed relevant, and at what stage of the skill acquisition process they become important, may be responsible for the absence of any observable perceptual training effect. Similarly, attempts to facilitate the selective attention process by systematically introducing irrelevant cues (e.g. Harrison & Reilly, 1975; Stallings, 1982, pp. 73-74; Stratton, 1978) have also been without a sound guiding base to this point.

Given now, as a consequence of the studies reported earlier in this thesis, the advantage of knowledge concerning both what the critical cues are in racquet sports, and how usage of these cues differs between experts and novices, it is obviously tempting to try to alter, through any of the previously discussed methods, the perceptual (selective attention) strategies of the novices so that they mirror those used by experts. Specifically, in the case of badminton examined here, this would involve increasing the novices' selective attention to arm-based information.

This concept of enhancing skill acquisition, by training lesser skilled performers to use the same cues as experts is an attractive one (Annett & Kay, 1956; Nettlefon, 1976), and is an apparently feasible one given that processing strategies appear to be under conscious control (Posner & Snyder, 1975), but it has a number of hidden difficulties. The most obvious problem of instantly altering the perceptual strategy of the novice to equate to that of the expert is with the discrepancy between
visual orientation and information extraction that has been noted at a number of previous stages throughout this thesis. Specifically it is quite pointless to orient the learners' attention to the arm if they do not have the necessary experience and knowledge of redundancies to meaningfully extract information from this cue source. Consequently for any imposed alteration in perceptual strategy for the novice it would seem essential to provide some additional knowledge of subjective probabilities and redundancies of the type which are normally only reliably developed over years of task-specific experience. Not surprisingly strategies which are self-imposed by the learner, rather than imposed by external instruction, are more likely to be retained over a period of time (Singer, 1980a; Singer & Gerson, 1981) and are more likely to be transferred by the performer from one situation to the next (Singer & Gaines, 1975), as in from the practice setting to the actual performance domain. It is, as Whiting (1979, p. 5) notes that

... in real-life situations people attach more importance to information they acquire through personal experience rather than through secondary sources

and this clearly makes alteration of the novice's existent perceptual strategy a difficult undertaking.

Genuine difficulties are often encountered in attempting to impose new strategies on sports performers (e.g. see Okwumabua, Meyers, Schleser & Cooke, 1983; Weinberg, Gould, Jackson & Barnes, 1980) and this may be a consequence of both this greater reliance that individuals place on their own prior experiences noted by Whiting and the associated failure of
imposed strategies to accommodate for the wide range of individual differences in strategy which exist at even apparently homogeneous skill levels. As it is extremely improbable that any two experts apply the same weightings to the available environmental cues, this makes determination of the ideal model of selective attention extremely difficult and complicates considerably the task of imposing the ideal perceptual model of performance upon the learner. Such a problem is indeed referred to in the classical writings of Bartlett (1947) who aptly observed that

The expert may discover his own key, the one thing or the few things that must be used with conscious effort and then everything else will happen right. The bother is that the expert is apt to treat his key as the master, whereas differences of bodily build, and consequently the mechanisms of bodily action, should make it clear that in this case, as in many others, one man's salvation is another man's downfall. (p. 877)

The differences between individuals are, of course, not only biomechanical as Bartlett notes but also perceptual in nature and it is these differences which compound the seemingly simple problem of modifying the perceptual strategy of the novice to equate with that of the expert.

Obviously then the role of training procedures in altering perceptual strategies and in effectively improving selective attention and anticipatory performance is worthy of considerable further research attention, as indeed is the associated question of the extent to which perceptual strategies acquired in any one racquet sport may be
meaningfully transferred to another (e.g. see Holding, 1965; Singer, 1980a).

C/ Future Directions

Like many research projects the experiments in this thesis have led to as many new questions as they have provided solutions, and a number of critical issues related to perception in racquet sports remain unanswered.

One particularly important unresolved issue relates to the extent to which information from peripheral vision contributes to the extraction of information critical to decision-making in racquet sports. In the methodology adopted in this thesis the role of peripheral inputs has not been clearly investigated in that the occlusion techniques only assess information extraction and do not differentiate foveal and peripheral retinal contributions, whereas the eye movement recording approach only assesses focal inputs. It may well be, however, that input to this area of the retina plays a large part in the perceptual analysis of the emerging stroke and that skills to utilize input which is non-foveal also need to be systematically acquired and developed in order for performance potential to be maximized.

In order to answer these questions of the role of foveal and peripheral inputs in normal information-extraction in applied skills such as racquet sports, it would appear necessary to have access to an experimental procedure in which the extraction of information from these two areas of the visual field could be manipulated during normal visual...
search activity. Appendix F presents the design logic for the development of such a procedure and outlines a number of predictions based upon existent two-mode theories of visual perception (e.g. Held, 1970; Ingle et. al., 1967; Leibowitz & Post, 1982; Schneider, 1969) which can be made regarding the respective roles of foveal and peripheral cues in prediction in badminton. Systematic investigation of the functional role of peripheral vision during information extraction in sports skills would seem particularly timely in view of the growing recognition of the limitations in existing sport science research on peripheral vision (e.g. Cockerill, 1981b; Davids, 1984; Potts, 1982; Rothstein, 1977a). Most existing studies have been restricted to simple static measurement of perimetric range (e.g. Graybiel et. al., 1955; Hobson & Henderson, 1941; Mizusawa, Sweeney & Knouse, 1983; Nettleton, 1979; Ridini, 1968; Stroup, 1957; Williams & Thirer, 1975) and reactivity (Buckfellew, 1954; Young & Skemp, 1959), and neglect to consider the ability of performers to actually use this information from the peripheral retina in perception and decision-making (e.g. see Davids, 1982; Holmes, Cohen, Haith & Morrison, 1977). (The reader is therefore directed to Appendix F for a more detailed proposal to examine the respective roles of the foveal and peripheral systems in information-extraction during dynamic visual search tasks of the type existing in racquet sports).

Hidden within this issue of the role of peripheral vision in racquet sport perception are some more fundamental questions relating to how relevant information is extracted from the various pertinent cue sources. Although some sound empirical data has been collected in this thesis
regarding the locus of pertinent information for experts it has also been noted that orientation of the novice’s attention to some of these sections of the display (specifically the racquet and the supporting arm) will not, in most cases, automatically bring about improved information-extraction. As visual orientation and information extraction are clearly not synonymous concepts the issue of how relevant information is extracted obviously needs resolving.

A particularly promising avenue in this respect may be to follow the lead provided by James Gibson in his theory of ecological optics in visual perception (Gibson, 1960, 1961, 1966, 1979). Searches for invariant optical variables fundamental to the perception of object flight and coincidence timing characteristics have been conducted with considerable success (Lee, 1980; Lee, Young, Reddish, Lough & Clayton, 1983; Schiff & Detwiler, 1979; Solomon, Carello & Turvey, 1984; Todd, 1981) and the parameter of time-to-contact information, based on the rate of dilation of the retinal image of the approaching object, appears fundamental to accurate visual perception and control of subsequent action (e.g. see also Lee, 1976, 1978; Lee & Lishman, 1977; Lee, Lishman & Thomson, 1982). However in light of the reliance which must be placed on advance cues for decision-making in fast ball sports, an equally important, but less investigated, issue becomes the means by which postural configurations of the opponent’s body and racquet are recognized and then used as a basis for stroke anticipation.

Determination of the invariant optical features of human posture and motion, such as in the original works of Johansson (1973, 1975), and more
recently in the works of Cutting (Cutting, 1981; Cutting & Kozlowski, 1977; Cutting, Proffitt & Kozlowski, 1978), Todd (1983), and Di Franco (1980), appears to be the logical direction for future applied research of this kind to proceed. This problem appears to run parallel to the problem identified in visual perception generally of ascertaining how the discrete sampling provided by human eye movements (Gaarder, 1975) allows a reliable 'picture' of the temporal and spatial characteristics of the changing environment to be established (Cohen, 1978a; Gould, 1976).

A number of other unresolved and related research issues are worthy of mention in closing, if only as an indication of possible future research directions and as recognition of the scope limitations of the results reported in this thesis.

Firstly, in view of the dominant role that vision plays in most perceptual-motor activities (e.g. see Colavita, 1974; Lee & Lishman, 1975; Posner, Nissen & Klein, 1976; Smyth & Marriott, 1982), and most certainly in fast ball sports such as badminton, the focus upon perceptual strategies examined in this thesis has concentrated on input from the visual modality. The visual world however clearly does not operate in isolation from the other modalities and perceptual analysis of the existing display is undoubtedly also dependent on the contribution of information from other relatively diverse sensory sources. An important omission from current knowledge, which is necessary to provide a more complete understanding of the perceptual analysis of the racquet sport display, is therefore understanding of the extent to which information from other modalities, especially auditory information (Cobner, 1981;
Docherty, 1973; Whiting, 1969, pp. 36-37), contributes to the prediction of forthcoming stroke direction and, further, how this information is integrated with the dominant visual input (see especially Craig, Colquhoun & Corcoran, 1976) to provide accurate response selection decisions.

Secondly, although the effects of stress and anxiety upon competitive sports performance are well documented (e.g. see Landers, 1980, 1982; Martens, 1971; Spielberger, 1971 for reviews) and the effect of stress in reducing the range of cues used in simple perceptual tasks has been frequently reported (Bacon, 1974; Easterbrook, 1959; Fuchs, 1962) there is currently a dearth of literature examining the effects of stress and anxiety upon cue usage in applied sports tasks (for an exception see Starkes & Allard, 1983). As available tests of attentional strategies (e.g. Nideffer's (1976) Test of Attentional and Interpersonal Style) do not appear capable of accurately predicting perceptual strategies in racquet sports (see Van Schoyck & Grasha, 1981), and as the effects of stress and anxiety are quite situation-specific (Martens, 1977), the development of an applied test paradigm for examining the effects of anxiety and stress on perceptual performance would seem particularly worthwhile. Extension of the paradigm developed in the course of this thesis to incorporate some means of inducing situation-specific stress (e.g. see Cox, 1984) would appear to open a viable avenue for the future examination of anxiety effects and perhaps also for the development and testing of situation-specific intervention techniques for stress inoculation.
D/ Conclusion : The Final Word

In conclusion, this thesis appears to have at least partially fulfilled its primary objectives in terms of identifying perceptual strategy differences between expert and novice racquet sport players. Specifically, experts have been shown to extract usable advance information at an earlier stage than novice counterparts and to place reliance upon one particular spatial area of the display for anticipatory information (the arm holding the racquet) which is not evident in the perceptual strategy of the novices. Some features of the perceptual strategies adopted for racquet sports which are independent of expertise have been identified and some implications for skill development and talent identification have been advanced. Finally, if for no other reason, the experimental series conducted has proven worthwhile in providing some positive directions for ongoing research and some emergent approaches to previously unresolved issues in sport perception. Resolution of these ongoing issues should further enhance our currently rudimentary knowledge of the relationship between sport proficiency and adopted perceptual strategies.
REFERENCES


Psychology, 60, 391-403.


Arbuthnot, J. (1972). Cautionary note on measurement of field


Bhanot, J.L., & Sidhu, L.S. (1980). Comparative study of reaction time
in Indian sportsmen specializing in hockey, volleyball, weightlifting and gymnastics. Journal of Sports Medicine and Physical Fitness, 20, 113-118. (a)


Blignant, C.J.H. (1979). The perception of hazard. II. The contribution of signal detection to hazard perception. Ergonomics, 22(11), 1177-1185. (b)


Brown, I.D. (1968). Criticisms of time-sharing techniques for


Docherty, E.M. (1973). The effects of reducing and masking the auditory cues accompanying performance of select gross motor tasks on the


Evarts, E.V. (1968). Relation of pyramidal tract activity to force exerted during voluntary movement. Journal of Neurophysiology, 31,


W. Prinz, & A.F. Sanders (Eds.) Cognition and Motor Processes (pp. 231-253). Berlin : Springer-Verlag.
Child Development, 38, 685-694.


Jackson, M. (1985). Sportspersons use of postural cues in rapid


Konzag, G. (1983). Diagnosis of action time in connection with sports-
relevant cognitive components of players in sport. Theory and
Practice of Physical Culture, 32(8), 592-597.


Paper presented at the annual meeting of the North American Society for Psychology of Sport and Physical Activity.


Miller, G.A. (1956). The magical number seven, plus or minus two: some limits on our capacity for processing information. Psychological Review, 63, 81-97.


Perlman, G. (1980). Data analysis programs for the UNIX operating system. Behavior Research Methods and Instrumentation, 12, 554-558.


Ryan, E.D. (1968). Reaction to "Sport and Personality Dynamics". In Proceedings of the National College Physical Education Association for Men (pp. 70-75).


Young, L.R., & Sheena, D. (1975). Survey of eye movement recording methods. Behavior Research Methods and Instrumentation, 7(5), 397-429. (a)


Zukowski, N. [Relationship between performance in judo and simple reaction time]. Sport Wycznowy, 16(1), 28-31.