An Examination of Neck Strength, Endurance, Neck Pain and Neck Stiffness in Rugby Union Players

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A thesis submitted for the degree of

Doctor of Philosophy

At the University of Otago, Dunedin

New Zealand

August 2014
Dedicated in Loving Memory to
Grandpa Wilson whose love
and support made
this possible
ABSTRACT

Background:

Rugby is a high speed collision sport during which the neck is often exposed to loads that place it at risk of injury. When injuries do occur they range from catastrophic injuries where permanent spinal cord damage may result, through to minor injuries where the primary symptom is neck pain (NP). As a potential preventative strategy it has been proposed that neck muscle strength and endurance may play a role in the prevention or mitigation of minor neck injury.

Aims:

The overall aim of this thesis was to explore the efficacy of a neck specific exercise intervention in improving neck neuromuscular function (neck muscle strength and endurance) and alleviating or minimizing symptoms of minor neck injury (neck pain and stiffness). To evaluate the efficacy of this intervention, a testing apparatus and an experimental protocol capable of reliably measuring neck strength and endurance were designed and developed. In order to address these aims, the thesis was constructed around a number of independent but linked research projects.

Methods:

A sequential multi-study approach was used to examine neck strength, endurance, NP and neck stiffness (NS) in rugby players. A critical review of the literature examined the existing neck injury surveillance data and potential factors or mechanisms that may play a role in the occurrence of neck injuries. A retrospective online survey was employed to examine the impact neck injuries sustained while playing rugby have on the subsequent health of retired players. A custom testing apparatus was designed and built to examine neck strength and endurance in a simulated contact posture, and its reliability established. This apparatus was then used with a cohort of amateur forwards, backs and healthy controls to examine the effect of a 20-week competitive season on neck neuromuscular performance. Evidence gathered from the thesis studies was used to design a neck exercise intervention for rugby players. The efficacy of this intervention was then examined in a cohort of professional rugby players using measures of neuromuscular function and perceived neck dysfunction (NP and NS) over
a competitive season and compared with a group of players who did not receive the intervention.

**Results:**

Neck pain and NS proved to be frequently reported current health complaints for retired professional rugby players. The majority of players surveyed sustained a neck injury (79%) during their careers. Of these, 91% reported currently experiencing symptoms of either NP and/or NS. These findings indicate that most professional players will sustain a neck injury and that this injury, or the accumulation of microtrauma in the neck region over their careers will have long-term health and disability consequences.

The testing apparatus developed assessed the neck isometrically in a simulated contact position. Assessment of neck strength over a single session revealed that, in the adopted body position, neck strength in the four examined directions could be reliably assessed using three trials ($ICC_{(3,1)}: 0.86-0.94$). To explore the test re-test reliability of the device, neck strength and endurance were assessed over three separate trials. The relative and absolute reliability for extension and flexion strength ($ICC_{(3,1)}: 0.92-0.97$; SEM: 11.27-15.27 N), and endurance ($ICC_{(3,1)}: 0.98$; SEM: 8.55-12.53 s) demonstrate that the apparatus can be used to reliably measure these parameters over time.

Over a competitive season neck strength and endurance was assessed in amateur rugby players and healthy controls. At the end of the competitive season improvements in strength for forwards and backs were observed ($p=0.01-0.05$), while the control group remained unchanged. No changes for the endurance measures were observed for the three groups over the season, which is likely attributable to the high individual variability found in these measures. Thus, participation in a season of amateur rugby appears to impose a physical stress on the neck musculature which leads to strength adaptation for amateur players. Proxy measures of neck dysfunction, NP and NS, were recorded at the start and end of the season. Both forwards and backs, reported increased NP ($p=0.01-0.04$), while only the backs reported increased NS over the season ($p=0.01-0.02$). These results suggest that despite improvements in neck strength over the season, both forwards’ and backs’ perceived neck function was impaired, while controls reported no change.

A neck specific exercise intervention consisting of exercises intended to improve neck muscle strength, endurance, and coordination, along with impulse loading of the neck, was
administered to a professional rugby team. In the intervention group neck strength ($p= 0.01-0.03$) and endurance ($p= 0.01$) was found to improve over the competitive season. In contrast, a professional control team that did not receive the intervention, displayed significant decreases in post-season neck strength and endurance, which coincided with increases in worst NP ($p= 0.05$) and average NS ($p= 0.02$). Despite the observed improvements in neck strength and endurance over the season in the intervention group, NP and NS scores remained unchanged. This data suggests that playing professional rugby imposes a large physical and perceived stresses on the neck, as evidenced by the impaired neck strength and endurance, and the increased post-season NP and NS scores. The prescription of and adherence to a neck strengthening exercise programme resulted in improvements in neck strength and endurance over a season, but did not change self-reported NP or NS. However, in this study the neck exercise intervention did prevent increases in symptom severity when compared to controls.

**Conclusion:**

Collectively, this corpus of work presents a number of interlinked studies relating to the exploration of neck strength, endurance, NP and NS in rugby players. The results from this research indicate that neck injuries sustained during a player’s career will likely impact on their subsequent health once retired. In comparison to other regions of the body the neck is a primary area of current pain and stiffness for retired professional players. In conclusion, the performance of neck specific exercises may provide a feasible strategy to reduce the occurrence of minor neck injuries in rugby players, which may improve their long-term health outcomes relating to neck disability and increase functionality in retirement.
REFEREE ABSTRACTS AND PRESENTATIONS


ACKNOWLEDGEMENTS

I promised myself that if I was going to do a PhD after my Masters it was going to have to be somewhere cool and doing something I really enjoyed. After a couple months of late nights and living in my office, I can say that this process has been an amazing experience and if given the opportunity I would do it again. I think this is a testament to the people I have met and the opportunities I have been provided throughout this PhD process, for which I am eternally grateful for.

First off I would like to thank my supervisor Phil Handcock for taking on the unknown from Canada. The people you have put me in touch with, your continually understanding with my constant bombard of questions and willingness to talk through problems has been greatly appreciated. John Sullivan you have been amazing through this process and I really appreciate all the time and effort you have given me. Your attention to detail and in-depth knowledge regarding the research process have held me in good stead and helped to develop me as a researcher. Nancy Rehrer thanks so much for all our long chats and your feedback throughout this process. I swear one day I will figure out if a word is possessive or not (though I would not put money on it!!). To Brian Niven I would have been up the proverbial ‘stats shit creek without a paddle’ if it had not been for you. The countless hours you spent with me working through the statistical analysis and discussing problems has taught me more than I ever learned in any stats class, I can’t thank you enough. To Don Sharpe your proof reading and stats help this last month has been a god send, I am still not sure where the hell to put a comma, but thank you so much for everything.

I would also like to thank Nigel Barrett and Gavin Kenney for their help with the design of the testing apparatus and development of the software, whether I was coming in because someone had ripped the head piece of the apparatus and smashed the lap top screen or if the software had crashed you both were always willing to go above and beyond and I truly appreciate it. To Charlie Blackie you are an IT god, your support and help with the development of our survey was legendary. I am definitely not sure the chocolate cake cuts the mustard to show my appreciation.

Karl Houltham you are a rock star and thanks so much for your help with recruiting amateur players, providing input into the design of the apparatus, support with the Super 15 study and most importantly holding me together it has all been greatly appreciated. To Peter Gallagher and Mike Cron thank you so much for your input into the design of the testing apparatus and
exercise intervention, your feedback has been greatly appreciated. To Peter, I owe you coffee. Thank you so much for your networking prowess, I would not have got as far as I did without you. Mike thank you for your passion and help with the neck strengthen side of the project. The opportunity to work with the under 20’s front row and the strings you pulled to get us a control group I am eternally grateful.

A special thanks to Craig McColl, Cam Shaw, Ian Murphy, Andrew Beardmore, Mark Hammett, Stephen Kara, and Mark Plummer for your help with the intervention project. Your time and support of this project was greatly appreciated and made this study possible. I would also like to thank the Highlanders, Hurricanes and Blues Super 15 organizations for inviting me into their team environment and allowing me to recruit players. To all the players who volunteered their time and participated, it would not have been possible without you.

To Josh Blackie and Rob Nichols thank so much for helping with the recruitment of retired players and support for the survey it would not have been as nearly as successful without you. To Dave Gibson, Rosemary Towner, Omar Hassenein, David Barnes, Caroline Guthrie, Graham Brown, Mark Lawson and Mike Chu your help with the distribution of the survey was greatly appreciated. To all the retired players who volunteered their time and completed the survey, I am very grateful.

To the University, Pirates, Southern and Alhambra Union Rugby Clubs your participation in the monitoring study was greatly appreciated. To the premier coaches and players who donated their time and participated the project would not have been possible without you. To all the university students from the School of Physical Education that volunteered to participate as controls thank you.

Finally I would like to thank my fellow postgrad students. This journey has had its ups and downs and you have been there throughout. To Paul Burch, Laurentius Meerhoff, Kim Meredith-Jones, Lisa Bavington, Terry Hill, Silke Neuman, Amanda Mullock, Rob Johns, Sarah Herring and Drew Carlton your help proof reading and formatting in theses last stages has been amazing. You guys have made these last couple of month much more enjoyable, I apologize for my English and lack of punctuation. To Stijn ter Welle, Terry, Joanna Cooper and Paddy Dempsey your help with data collection and your general support throughout the PhD was legendary, thank you so much. Rens you have kept me sane particularly through this last year thank you so much for all your help with the little things you are amazing.
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LIST OF ABBREVIATIONS

%AUC: Percent area under the force curve
A: Amateur
ANOVA: Analysis of variance
AS: Anterior scalene
B: Backs
BMI: Body mass index
C-CF: Cranio-cervical flexion
CJPS: Cervical joint positioning sense
CON: Control group
DNF: Deep neck flexors
EMG: Electromyography
Ext: Extension
F: Forwards
Flx: Flexion
Gz: Gravitational force
HA: High adherers
kg: Kilogram
LA: Low adherers
LtFlx: Left lateral flexion
ICC: Intra-class Correlation Coefficient
IRB: International Rugby Union Board
MDC: Minimal detectable change
mm: Millimetre
ms: Millisecond
MRI: Magnetic resonance imaging
MVC: Maximal voluntary contraction
N: Newton
NDI: Neck Disability Index
NFL: National football league
NG: Neck intervention group
NME: neuromuscular efficiency
NP: Neck pain
NS: Neck stiffness
P: Professional
RM: Repetition maximum
ROM: Range of motion
RtFlx: Right lateral flexion
s: Second
SCM: Sternocleidomastoid
SD: Standard deviation
SEM: Standard error of measurement
TTF: Time to fatigue
VAS: Visual analogue scale
wks: Weeks
yrs: Years
Δ: Difference
LIST OF DEFINITIONS

Neuromuscular variables: neck strength and neck muscular endurance.

Perceived neck muscle dysfunction: neck pain and neck stiffness.

Rugby: 15-a-side rugby union.

Backs: rugby positions 9 through 15

Forwards: rugby positions 1 through 8

American gridiron: American football.

Pain: an unpleasant sensory and emotional experience associated with actual or potential tissue damage (1).

Neck pain: defined as pain perceived as originating in the region bounded superiorly by the superior nuchal line and inferiorly by an invisible transverse line traveling through the spinous process of the first thoracic vertebra (2).

Stiffness: the resistance that the joint offers during movements or when starting a movement (3). This definition also includes feelings of tightness and/or resistance to stretch in the musculature in the absence of pain (3).

Normalization: refers to the adjustment of the examined physiological measure (peak force or endurance) to control for the contribution of body size (age, height, weight, neck girth) to the overall variation in the data (4).

Area under the curve: was used as an index of cervical muscle fatigue during each endurance trial and was calculated using MATLAB (MathWorks@, Natick, MA) and the trapezium rule method.

Time to fatigue: was the length of time in seconds the submaximal force was maintained prior to terminating the test by either reaching the 3 min mark or when a participant dropped below the 70 ± 5% mark for more than 4 s (5, 6).
Chapter 1

Introduction
“If we knew what it was we were doing, it would not be called research, would it?”

~ Albert Einstein

1.1 Background and Context

The origins of rugby union are often disputed, with some proponents claiming its beginnings in football games played at fairs and festivals (7). Others state that rugby began when William Webb Ellis first picked up the ball and ran with it in 1823 (8). Despite its contested origins, rugby union has evolved to become a modern collision sport played throughout the world (9-11). This sport involves periods of submaximal activity such as walking and jogging interspersed with short bouts of high intensity activities involving sprinting, tackling, rucking and mauling (12). The governing body for rugby union, the International Rugby Board (IRB), currently has 117 participating countries with approximately 3.5 million players including men, women and children from the age of 6 to 60 (9, 13). There are variations of rugby played, ranging from Under 19, seven-a-side to ten-a-side where the rules and regulations are modified (13). For the purposes of this thesis, only 15-a-side rugby union will be examined, and the term rugby will refer to rugby union.

Proponents of the modern day version of the game state that rugby has evolved to become more physically demanding due to the increased amount of time the ball is in play, the speed of play, impact forces during collisions, and the increased frequency of tackles and rucks (9, 10, 14, 15). In addition to these changes to the dynamics of the game, the physique of players has evolved with an average increase of 2.6 kg in body mass and 0.4 kg·m⁻² in body mass index (BMI) per decade (15-17). Evaluation of Rugby World Cup standings from 1987-2007 have also revealed an association between increased mass and BMI of the players and the subsequent success of the team (16, 17). When players of increased body mass are running, the expected collision forces are higher and the likelihood that these forces exceed the tensile strength of a tissue or joint resulting in injury is greater. These findings would extend to injuries sustained at the head/neck region (18, 19), which for professional players is the 2nd most frequently injured anatomical region (20). The focus of this thesis is on the assessment of these neuromuscular variables (neck strength and endurance) over a competitive rugby season, and the design and implementation of a neck specific
exercise intervention for the prevention and/or mitigation of minor neck injuries in rugby players. In order to conduct a comprehensive assessment of the intervention, self-reported neck pain (NP) and neck stiffness (NS) were used as indicators of perceived dysfunction and impairment in this region.

This thesis has been designed loosely based around the injury prevention framework introduced by van Mechelen in 1992 titled the ‘Sequence of Prevention’ (21). Recently this model has been updated to a research framework that focuses on ‘Translating of Research into Injury Prevention Practice’ (22). Despite this modification to van Mechelen’s original model, the first three stages remained unaltered. Phase 1 encompasses injury surveillance, conducted to identify and describe the extent of the examined sports injury problem. Phase 2 involves identification of the factors and mechanisms that play a role or influence the occurrence of the observed sport injury. The third and final phase in the original framework involves the implementation or introduction of rule changes, equipment, injury prevention programs or training protocols to reduce the future risk and/or severity of the sport injury as guided by evidence from Phases 1 and 2 (21).

With respect to the Phase 1 examination of injury frequency and occurrence in rugby, the focus of neck injury surveillance efforts have been directed towards the occurrence of catastrophic neck injuries resulting in permanent neurological impairments (23-28). While these events are infrequent, the health outcomes are often devastating (24, 26, 29-31), thus the IRB and its subsidiary members have adopted rule changes, educated players and coaches, and modified elements of the game (including the scrum) in an attempt to reduce the frequency of these events with varying degrees of success (32, 33). However, the majority of neck injuries sustained in rugby at both the amateur and professional level are classified as ‘minor’ in severity but occur relatively frequently (20, 29, 30, 34-36). Despite the frequency of these injuries, they have received little attention in the literature (24, 37).

Research examining the symptoms of minor neck injuries has reported that the most commonly cited symptom is NP (2). Neck pain has been defined as pain perceived as originating in the region bounded superiorly by the superior nuchal line and inferiorly by an invisible transverse line traveling through the spinous process of the first thoracic vertebra (2). In a review examining the pathophysiology of NP Bogduk (2) provides a
comprehensive discussion on identified causes of NP ranging from vertebral tumors to fibromyalgia. However, in many instances, the origin and precise pathophysiological mechanism(s) of NP remain obscure. Most research indicates multifactorial origins, including external psychosocial and physical loading factors, as well as the psychological and biological characteristics of the particular individual (2, 38-43). Some plausible causative factors have been identified, such as muscle degeneration and/or impaired neuromuscular function resulting from chronic overuse, which are frequently accompanied by symptoms of pain, muscular weakness and fatigue (39). In addition, degenerative changes in the cervical vertebrae and discs, and nerve impingement may also lead to the expression of NP (42).

In rugby, NP has only been examined in a single observational study of an amateur rugby cohort. In that study, Gemmell et al. (44) reported that NP affected 83% of forwards and 41% of backs. These findings are substantially higher than the prevalence reported for the general adult population (15-74 yrs of age) that ranges from 5.9-22.2%, with a mean prevalence of 7.6% (45). Given that forwards sustain a greater percentage of neck injuries than backs (27, 30, 36, 46), the higher prevalence of NP in this group of players is not unexpected. Despite this discrepancy in NP prevalence between the two positional groups, examination of the cervical region using magnetic resonance imaging has identified pathological changes to the osteoligamentous system in both forwards and backs (47). In addition to these osteoligamentous changes, research has also reported impaired cervical range of motion (44, 48-50) and cervical proprioception (44, 51).

The question then becomes does repeated microtrauma to the neck from rugby participation cause chronic degenerative changes and result in increased symptomatology or related disability for these players? A recent study (37) compared the cervical spine radiographs obtained in high level (provincial and international) front row players ($n=14$) to sex and age matched controls ($n=14$), all of whom presented to emergency departments with acute neck injuries over a two-year period. The authors reported that front row forwards exhibited significantly greater radiographic evidence of degenerative changes in the disc spaces and apophyseal joints of the cervical spine when compared to the controls. However, there was no difference between the rugby players and the controls with regards to NP, neurological symptoms or effects on
activities of daily living (37). These findings may be explained by an under-reporting of NP and/or disability relating to NP symptoms by the rugby cohort. Thus, to further explore the impact of these osteoligamentous and neuromuscular impairments in the cervical spine, the construct of NS has been introduced and developed as a global measure of neck function. For this thesis, NS was defined as the resistance that the neck offers during movements or when starting a movement (3). This definition was expanded to include feelings of tightness and/or resistance to stretch in the neck musculature in the absence of pain (3). Use of this construct may permit the identification of individuals who may have adapted to the constant level of pain in the neck and while not reporting pain are still experiencing some level of impairment in the affected region. Use of these measurement constructs (NP and NS) provide a quantitative means to examine whether a focused training program can lead to changes in perceived dysfunction of the neck in rugby players, which is the primary focus of this thesis.

Given the frequency of minor neck injuries and the catastrophic consequences of severe neck injuries (11, 24, 30, 36, 46, 52), a number of position papers have recommended the incorporation of neck exercise into training regimes as a method for injury prevention (53-57). However, this recommendation is based on limited scientific evidence. Thus, to examine the effectiveness of a neck exercise intervention, measures of neuromuscular function are required such as neck strength and endurance. Neck strength has been defined as the ability of the cervical muscles to exert a maximal force either isometrically or dynamically (58, 59), while neck muscle endurance is defined as the ability to sustain submaximal contractions repeatedly or to generate force over a given period of time (59). Research examining neck strength and endurance has used these neuromuscular parameters as indicators of neck muscle dysfunction (60-64). A number of studies have demonstrated reduced peak force, endurance capacity, and neuromuscular efficiency in individuals with chronic NP, whiplash, headaches and other neck/shoulder disorders (5, 42, 65-71). Yet other research has documented no changes in NP symptoms following improvements in neck strength, highlighting the controversy surrounding the relationship between these two variables (58, 59, 64, 72). Despite the controversy surrounding neck strength and the occurrence of NP symptoms, most researchers and clinicians agree on the use of neck strength to evaluate the impact of a season or an intervention (58, 59).
Only recently has the impact of a neck specific exercise protocol in a professional rugby team been demonstrated with respect to the occurrence of neck injuries sustained during game play over a season (73). The majority of research examining neck strength in rugby is limited to single observational studies (74-76). Currently there is no evidence of what ‘normally’ happens to neck strength or endurance over a season or after the application of an intervention. In addition, the perceived dysfunction of the neck over the season using measures of NP and/or NS have not been previously examined.

Research in other populations has documented impaired neuromuscular function in individuals with NP (5, 43, 61, 65, 71, 77, 78). Numerous mechanisms have been investigated in an attempt to explain alterations in muscle behaviour observed in the presence of pain (79, 80). Lund et al. (79) proposed ‘The Pain-Adaptation Model’ to explain the observed changes in muscle activity caused by chronic pain. This model proposes that when pain is experienced in a muscle or joint, the motor command facilitates an inhibition pathway to the affected agonist motor neurons, an excitatory pathway to the antagonist motor neurons and an inhibition of the antagonist subgroup of interneurons. Activation of these pathways leads to a decreased motor neuron output in the agonist muscles and an increased output in the antagonist muscles, resulting in a reduction in peak force, range and velocity of movement (79, 81, 82), endurance time during submaximal contractions, and muscle co-ordination during dynamic exercise (81). However, the impact of NP on motor behaviour in the neck musculature of rugby players has not been previously examined.

1.2 Thesis Aims

The overall aim of this thesis was to design and develop a neck specific exercise intervention for professional rugby players. In order to evaluate the efficacy of the intervention, a testing apparatus and experimental protocol capable of measuring neck strength and endurance were designed and developed. This apparatus was then used to evaluate the effect of a season with and without a neck specific exercise intervention in rugby players. In addition to these measures of neuromuscular function, perceived dysfunction of the neck was also examined using NP and NS to observe any detrimental effects of a season of competition and to gauge the success of the
intervention. In order to address these aims, the thesis was constructed around a number of independent but closely linked sections (Chapters).

**1.3 Research Questions**

**Review of literature (Chapter 2).** The starting point of this thesis was to search and critically review the literature related to the topic area. This Chapter examines the following: the sport of rugby and the effects that professionalization has had on the game in terms of player development and frequency of injuries since 1995. To fully explore the relationship between strength and symptoms of minor neck injuries, an understanding of the anatomy of the cervical spine and the role that the osteoligamentous and neuromuscular systems play in the stabilization of this region is essential. Following this examination, research on the impact of rugby participation on the structure and functioning of these systems was reviewed. This led to a discussion of neck injuries in rugby, the frequency of these events, players most at risk, mechanisms of injury, and the phase of play where these events most often occur. A discussion of the methodological considerations surrounding assessment of cervical strength and endurance followed and the Chapter concludes with a focus on the current evidence surrounding the relationship between strength/endurance and the occurrence of injuries and/or pain. As the primary outcome of this research is the development of a neck specific intervention for rugby players, the final section of this review examines the role a neck specific intervention may have on self-reported NP and/or NS.

**Long-term consequence of neck injuries in rugby (Chapter 3).** To establish whether NP and NS was a health concern for players once they retired, the health status of retired professional rugby players was examined. The primary purposes of this chapter were the following:

1. To retrospectively document the number of cervical injuries sustained during playing careers,
2. To retrospectively document the number of cervical injuries sustained during playing careers that required surgical interventions,
3. To explore the use of specific neck exercises in the treatment of neck injuries,
4. To investigate current NP and NS in retired professional rugby players,
5. To examine retired professional rugby players’ levels of chronic NP and disability using the NDI.

The injury surveillance literature has indicated that forwards sustain proportionally a higher number of neck injuries when compared to backs (20, 27, 30, 52). Despite this discrepancy with regards to injury frequency, players in both positions present with documented changes in the cervical osteoligamentous and neuromuscular systems (47, 48, 51). Thus, the secondary purpose of this study was to compare the level of current NP, current NS and NDI scores in forwards and backs.

**Experimental protocol and design of the fixed frame dynamometer to assess neck strength and endurance in a simulated contact posture (Chapter 4).** In order to evaluate neck muscle strength and endurance, Chapter 4 examined the design and development of a testing apparatus and assessment of the test-retest reliability of the device. Chapter 4 consists of two separate studies Parts I and II. The focus of Part I was the design of the apparatus and reliability over a single session. The focus of Part II was the test re-test reliability of the device and experimental protocol over three separate sessions.

**Part I:** The purpose of this study was to:

1. To develop a functional and reliable testing apparatus and experimental protocol that would permit evaluation of neck musculature maximal force production in a simulated body contact position.

2. To establish the within day reliability of repeated measurement with this device.

This testing posture was based on the body position adopted during contact events such as tackling, scrummaging, rucking, and/or mauling, and the propensity for these events to result in injury to the cervical spine. Peak force production of the cervical spine was examined in four movement directions over three repeated trials during a single testing session. Reliability of this novel testing apparatus was assessed through the use of relative and absolute reliability parameters.

**Part II:** The purpose of Part II was to:
1. Examine the reliability of repeated measurements of neck strength and endurance over three testing sessions using a testing apparatus considered functionally relevant for collision.

2. Analyse isometric peak force and endurance values in Flx and Ext to examine variations in patterns or trends that may exist across the repeated sessions for the two directions.

Monitoring of: Neck strength, endurance, neck pain and stiffness over a season in a cohort of amateur rugby players and controls (Chapter 5). Following the design of the reliable tool to evaluate neck strength and endurance, the primary purpose of this study was to monitor these measures over a competitive season in a cohort of male amateur rugby players (forwards and backs) relative to healthy control group. In conjunction with measures of strength and endurance, changes in current, average, and worst NP and NS were monitored over a competitive season in the rugby cohort and controls. If the cervical musculature plays a role in injury prevention, it is essential to monitor the functional capacity of these muscles in order to observe improvements or decrements resulting from exposure to a season of rugby.

The secondary purpose was to evaluate the relative and absolute reliability of the measures to determine whether improvements or decrements in performance had occurred over the season.

Design of a neck specific exercise intervention for rugby (Chapter 6). This chapter described the design of a neck specific intervention for rugby players. The primary purpose of the neck exercise intervention was to design a protocol that would improve neck strength and endurance in professional rugby players and potentially mitigate symptoms of NP and NS. The intervention program incorporated exercises that focused on four key areas: (a) neck muscle strength, (b) neck muscular endurance, (c) neck muscle coordination, and (d) impulse loading of the neck.

An examination of a neck specific intervention in a professional rugby team relative to a control (Chapter 7). The primary aim of this study was to examine the efficacy of a neck specific exercise intervention in a professional rugby team. As the situation did not allow for the recruitment of a matched control group who would be available for testing over the same period of time, a non-matched (temporally) group of
professional rugby players (control group) was used as a point of comparison. In order to examine the efficacy of the neck exercise intervention, pre- and post-season neck strength and endurance measurements were conducted. In addition to measures of neuromuscular function, changes in current, average, and worst NP and NS were also monitored pre- and post-season. For the strength and endurances measures, relative and absolute reliability values were calculated to statistically determine whether improvements or decrements in performance had occurred over the season in the two groups.

The secondary aim of this study was to explore the effect training adherence had on those in the neck intervention group. If the cervical musculature plays a role in injury prevention, it is essential to monitor the functional capacity of these muscles in order to observe improvements or decrements resulting from exposure to a neck specific intervention relative to a control group.

1.4 Research Pathway

Research has documented changes in the osteoligamentous system and impairments in neuromuscular function in the necks of active rugby players (44, 47, 48, 51, 83). Thus, the first study in this thesis (Chapter 3) employed a retrospective survey to examine the long-term health and disability of retired professional rugby players relating to symptoms of NP and NS. Respondents were asked to recall neck injury information from their rugby career and this recollection was used to explore whether their past injury history had any long-term health consequences or impaired their ability to complete tasks of daily living. This study was conducted to establish the prevalence of NP and NS prior to examination of Phase 1, 2, and 3 and their relation to minor neck injuries. The relationship between the various chapters and van Mechelen’s ‘Sequence of Prevention’ model is illustrated in Figure 1.1.

As rugby injury surveillance data have reported that the incidence of neck injuries ranges from 0.5 to 10.58 injuries/1000 player-hours (30, 34, 36, 46, 84), the present studies (Chapter 4 and 5) were designed to explore mechanisms or factors that may contributed to the occurrence of neck injuries. Specifically, these studies focused on neck musculature strength and endurance and the role these neuromuscular variables may play in injury prevention. Review of the literature revealed a number of position
papers that highlight the potential importance of neck musculature function as an avenue for the prevention of minor neck injuries (53-57, 85, 86), yet there is little scientific evidence to support this claim. Fundament to this thesis is a means to reliably monitor changes in neck strength and endurance that occur over a season or after the application of a neck exercise intervention. Thus, Chapter 4 described the design of a testing apparatus and the development of an experimental protocol to assess neck strength and submaximal endurance in a body position that has practical relevance to rugby.

Neck strength in rugby players has only been examined at a single point in time (74-76). Currently there is no evidence to indicate what happens to neck strength over a season. Given that injury surveillance data at the amateur level indicate that the frequency of neck injuries decrease as the season progresses (87), there may exist a parallel changed in neuromuscular function of the neck over the season. If there is a relationship between the frequency of neck injuries and neck strength and endurance, it is essential to observer what happens to these parameters over the season. Therefore, the purpose of Chapter 5 was to monitor neck strength and endurance of amateur forwards and backs over the length of a competitive season relative to a healthy non-rugby control using the testing equipment and protocols detailed in Chapter 4. In addition to measures of neck strength and endurance, self-reported NP and NS were also recorded at the start and end of the season.
Figure 1.1: Adaptation of the van Mechelen’s (21) ‘Sequence of Prevention’ relative to information and studies conducted in this thesis.
The final phase in van Mechelen’s ‘Sequence of Prevention’ model involves the introduction of preventative measures. Guided by evidence from the following areas (a) neck injury surveillance data (30, 36, 87); (b) intervention studies in rugby (73, 88), other sports (89-92) and populations (61, 65, 71, 93, 94); and (c) position papers (54-57), a specific neck exercise intervention program for rugby players was designed. Chapter 6 provides the theoretical background and justification for the four main components of the intervention program: (a) muscle coordination focusing on the deep cervical stabilizers, (b) neck muscle endurance through a dynamic range of motion, (c) isometric strength in a neutral position, and (d) impulsive loading using low level resistance in a neutral neck position.

The final study of this thesis was a preliminary examination of the efficacy of a neck specific exercise program implemented over a season in a professional rugby union team compared to a non-matched control team (Chapter 7). Neck strength, endurance, NP and NS were recorded pre- and post-season in both teams and were used to evaluate the efficacy of the neck exercise program. The neck exercise intervention was implemented on a regular basis (2-3 x per week) during the pre-season and in-season (1-2 x per week). The thesis concludes with an overall summary of the findings from the studies, a discussion of the strength and limitations of this research, and future research directions (Chapter 8).

1.5 Significance of this Research

A multifaceted approach to examine neck strength, endurance, NP and NS in rugby was employed in the research presented in this thesis. The data from the retrospective survey (Chapter 3) provide the first initial insight into the effect of neck injuries sustained during a player’s career has on their ability to complete activities of daily living and their current health status. The information collected in this survey can be used to facilitate examination of rules and regulations of the game by governing bodies to allow the implementation of changes to prioritise players’ current and long-term health outcomes. The results can also be used to help guide rehabilitation protocols and programs for future and currently retired athletes to reduce the impact of identified health concerns.

The testing apparatus designed for this thesis provides a reliable and simple method for the assessment of neck strength and endurance in a field-based setting for rugby players. The apparatus measures these neuromuscular variables in a practically relevant body position (simulated contact body posture) which can be used to examine the impact of a competitive
rugby season or the prescription of a neck exercise intervention. This apparatus builds on previous work, primarily conducted with players in the seated position (74-76, 90, 91, 95). Isometric neck strength assessment using a fixed frame dynamometer is referred to as the gold standard for the development of normative strength values (58, 59). In addition, the strength and endurance values recorded using this apparatus can be employed as normative values to assess neck function subsequent to injury or as a basis for comparison with other portable devices such as the handheld dynamometer.

The design of the exercise intervention used in this thesis was based on research and injury patterns observed in rugby. The examination of this exercise intervention in professional rugby players over a season provides the first step to explore the relationship between neuromuscular function and self-reported NP and NS. In addition, an investigation into efficacy of this neck specific exercise intervention provides a foundation for future research to evaluate the effectiveness of these exercises to reduce or mitigate the occurrence of minor neck injuries. The application of this exercise protocol would not be limited to rugby but would also be relevant for other collision based sports such as hockey, American gridiron, rugby league and football.

1.6 Summary

The underlying framework of this thesis is based on van Mechelen’s ‘Sequence of Prevention’ model with the primary aim of developing a neck specific intervention for rugby players to reduce and/or mitigate symptoms of NP and NS. Collectively, this corpus of work generated a series of interlinked studies relating to the exploration of neck strength and endurance, NP and NS in rugby players. The variety of methodological approaches employed in this thesis ensures a comprehensive review of neck injuries, their contributing factors and their contribution to the health of retired professional rugby players.


2.1 Introduction

Rugby is a high-speed collision sport where the cervical spine is potentially and repeatedly exposed to forces that can result in injury (27). Typically, the ligamentous and muscular system are able to absorb and dissipate these forces through controlled motion. However, injury occurs when the neck position, weakness in the muscular or ligamentous systems, or structural deformities compromise this ability (53). Neck injuries sustained during rugby range from minor impairments where complete recovery is expected, through to severe catastrophic injuries encompassing permanent neurological disability, paralysis, and occasionally death (27, 96). Despite the substantial human and medical burden of catastrophic cervical injuries, they occur relatively infrequently in sport (97). Rather, the majority of neck injuries in rugby are classified as minor in severity (30, 34, 36). Although minor injuries constitute the largest percentage of injuries the majority of research has been directed toward catastrophic neck injuries (88, 97, 98). Once a player has sustained a neck injury they are at an increased risk of sustaining future, potentially more severe, neck injuries (36). Long-term the likelihood that sustaining these repeated minor neck injuries leads to the development of pathological changes in the cervical spine is an area of concern for both medical and rehabilitation professionals (47, 83, 98). Therefore the purpose of this Chapter was to examine the potential role that cervical strength may play in the prevention or minimization of the primary symptoms of minor neck injuries, namely neck pain (NP) and/or neck stiffness (NS).

This Chapter examines: the sport of rugby and the effects that professionalization has had on the game in terms of player development and frequency of injuries since 1995. To fully explore the relationship between strength and symptoms of minor neck injuries, an understanding of the anatomy of the cervical spine and the role that the osteoligamentous and neuromuscular systems play in the stabilization of this region is essential. Following this examination, research on the impact of rugby participation on the structure and functioning of these systems was reviewed. This led to a discussion of neck injuries in rugby, the frequency of these events, players most at risk, mechanisms of injury, and the phase of play where these events most often occur. A discussion of the methodological considerations surrounding assessment of cervical strength and endurance followed and the Chapter concludes with a focus on the current evidence surrounding the relationship between strength/endurance and the occurrence of injuries and/or pain. As the primary outcome of this research is the
development of a neck specific intervention for rugby players, the final section of this review examines the role a neck specific intervention may have on self-reported NP and/or NS.

### 2.2 Methodology

A comprehensive examination of the relevant literature relating to neck strength, neck endurance, neck exercise interventions, neck injury and neck pain in athletes was conducted. PubMed, Ovoid, Psych INFO, Web of Science, Medline, Sport Discus, Google Scholar and Cochrane Library databases were reviewed. This process took place at multiple times over the duration of the thesis and a range of alerts and citation searches were conducted. Relevant sources were identified using the following criteria:

- Access to English full text articles
- Inclusion of the term ‘neck’ with each of the following terms ‘rugby’, ‘athletes’, ‘sports’, ‘neck injuries’, ‘injury surveillance’, ‘exercise therapy’, ‘exercise intervention’, ‘neck strengthening’, ‘neck endurance’ , and ‘neck pain’ were the key search strategies
- 1980 - Present
- The bibliographies of the selected articles were also manually examined to identify additional articles not located by the above search strategies.

### 2.3 The Sport of Rugby Union

Rugby is a sport that involves considerable physical contact between opposing players (99). During the game two teams of 15 individuals use backwards passing, running with the ball, grounding and kicking in an attempt to advance the oval shaped ball across the opposing teams’ try line to score points. The defending team will try to re-gain possession of the ball or attempt to stop/slow the forward progression of the offending team by tackling the ball carrier. Each team is generally classified into two groups of players, forwards (Numbers 1 through 8) and backs (Numbers 9 through 15), for a list of positions refer to Figure 2.1. Typically the forwards are characterized as the larger and stronger individuals as they are required to engage in scrummaging and a large majority of the tackling, rucking and mauling. Conversely, the backs are normally smaller and faster individuals, who make the long runs and break through the defending teams’ line (13).
In rugby, tackling is the most common form of contact between players (20, 100). Tackling occurs when a player from the opposing team attempts to stop the ball carrier with the use of his/her arms (100). Another form of established contact is the scrum, a set play that occurs after a break down in the game, where the two opposing forward groups bind together and compete to win the ball with their feet. Other forms of contact that occur during a game include: collisions (where a player from the opposing team attempts to stop the ball carrier without the use of their arms) (100), rucks (where one or more players from each team, who are on their feet and in physical contact, close around the ball on the ground), mauls (which consist of at least three players, all on their feet and occurs when a player carrying the ball is held by one or more opponents, and one or more of the ball carrier’s team mates bind on the ball carrier) and line-outs (where players from the opposing team line up in two lines a metre apart and compete for possession of the ball when the ball has left the field of play) (13).

2.4 The Effect of Professionalization on Rugby Union

The study of professional athletes offers a unique opportunity to evaluate the long-term impact of sport participation. In most instances these individuals have participated for a prolonged period and at the highest level of competition. Research on the health status of retired professional athletes has focused primarily on football (soccer) (101, 102), American gridiron (American football) (103-106), baseball (107) and boxing (108, 109). Collectively the findings from these retrospective surveys have identified the existence of a relationship

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**Figure 2.1:** Player positions on a rugby team
between the number of injuries sustained during an athlete’s career and the existence of future health related concerns for that individual.

Professionalization of the sport in 1995 removed restrictions on player payment, enabling players to focus more time and effort on physical conditioning and training for rugby (110). This in parallel with scientific advancements in exercise science and rehabilitation, has produced stronger, faster, and more skilled athletes (110, 111). If an individual increases their training time and competes against others who are also faster, stronger and who possess a higher skill level, the risk of experiencing an injury likely increases despite the improvements in strength and fitness of the players (99). Support for this argument is provided by injury surveillance data for the Australian national rugby team, where after professionalization of the sport (1994-95) injuries increased from 47 to 74 injuries/1000 player hours of game play during the 1996-2000 seasons (111). Garraway et al. (110) conducted an injury surveillance of the senior rugby clubs during the 1993-94 season and again in 1997-98 season after professionalization of the sport (population included professionals and amateurs). They defined an injury as “an event sustained during a competitive match which prevented the player from training or playing rugby from the time of the injury or from the end of the match in which the injury was sustained” (110). An injury was recorded every 3.4 matches during the 1993-94 season. For the entire sample population of amateurs and professionals, this increased to an injury every 2.0 matches during the 1997-98 season. When isolated for professional players the number rose further to an injury event every 59 minutes of game play. Although professional players had an average of 15% more hours of game time than amateur players, this could not solely explain the injury discrepancies between the groups (110).

A study in which injury rates in professional and amateur rugby players were examined during the 1993-94 and 1997-98 seasons in Scotland reported that new injuries were the most common in the 1993-94 season. In the 1997-98 season, recurrent injuries were more predominant than new injuries for professionals and increased substantially for amateur players (110). Most neck injuries occurred during the tackle phase of the game for both professional (112) and amateur players (110). Being tackled has been linked to a higher incidence of injury for professional players than amateurs, particularly for those individuals playing in the loose forward positions (6, 7 and 8) (112). Despite a decrease in the total game time from the 1993-94 to the 1997-98 season of 1,737 hours, no spinal injuries were reported...
in the 1993-94 season while two cervical spine dislocations occurred during the 1997-98 season (110). These statistics combine to highlight the elevated risk of injury involved with playing rugby, particularly for those playing professionally. This also emphasizes the need to address the occurrence of recurrent injuries and to examine the potential role physical fitness and evidence based rehabilitation protocols may play in the prevention and treatment of injury.

Currently there is little research examining the long-term health impact of participation in rugby. One of the few studies to examine the effect of rugby injuries had on health and participants’ lifestyles was performed in the Reivers District of the Scottish Rugby Union (113). The study retrospectively examined the impact injuries sustained during the 1993-94 season had on the player’s health status four years later. A total of 911 participants responded, and of these, 35% \((n=91)\) reported that the injury had a “temporary or significant effect on [their] education, employment, family life, or health and general fitness” (113). Over the study’s four year period, 390 individuals retired from the sport. One of the most common reasons attributed to retirement across all the age groups (< 20, 20-24, 25-29, > 30) examined was ‘injuries sustained while playing rugby’ (113). Collectively, these findings begin to highlight the effects injuries have on participants’ quality of life, their family environment, and their decision to retire from rugby.

2.5 Anatomy of the Cervical Spine

The cervical region of the human spine has evolved to perform three basic functions: carry large loads, allow the head to move in multiple directions, and protect the nerves located within the spinal canal while performing these functions (114, 115). To accomplish these tasks the cervical spine must be mechanically stable when generating isometric and dynamic contractions for movement of the head-neck segment or the maintenance of head postures (61). Stability in this region of the spine is a function of “the inherent passive stability of the spinal column and the highly developed active stability provided by the surrounding muscles” (115).

2.5.1 Osteoligamentous system

The cervical vertebrae are the smallest and lightest vertebrae of the spine (116). The first two cervical vertebrae, the atlas and axis, are unique in that they have no intervertebral disc
separating them, and are highly modified, reflecting their specialized function. The remaining cervical vertebrae C3 through to C7 are known as typical cervical vertebrae and have: (a) an oval body, (b) a bifid spinous process that projects posteriorly, with the exception of C7, (c) a large vertebral foramen, and (d) transverse processes that contain the transverse foramen (Figure 2.2). Due to the unique characteristics of its vertebrae, osteoligamentous system, and surrounding musculature, the cervical region of the spine has the greatest range of motion (ROM). This range encompasses flexion (Flx), extension (Ext), rotation, and lateral flexion movements, with typical ROM of approximately 145° in Flx/Ext and 180° in rotation (116). Most of the rotation permitted by the cervical vertebrae occurs between the C1-C2 joints, whereas the C3-C7 joints are primarily responsible for Flx and Ext (117). The increased mobility of this region of the spine comes at the cost of stability, placing the cervical spine at an increased risk of injury relative to the other spinal regions (116).

![Figure 2.2: The cervical vertebrae](image)

### 2.5.2 Cervical musculature

The musculoskeletal system of the cervical spine is one of the most complex and dynamic systems in the human body. The marked morphological diversity of the cervical muscles permits the control of a wide variety of head movements. Panjabi et al. (115) found that the osteoligamentous system contributes approximately 20% to the overall stability of the neck.
while the remaining 80% is provided by the surrounding musculature. In the osteoligamentous system, the ligaments mainly provide stability at the end of the range of motion (118), while the muscles function to “supply dynamic support in activities around the neutral and mid-range postures, postures that are commonly adopted during functional daily tasks” (61). Based on their moment-generating capacity, the muscles of the cervical spine can be classified as either segmental stabilizers or prime movers. The muscles surrounding the cervical vertebrae of the spinal column are classified as segmental stabilizers, which provide postural support for cervical lordosis and the cervical joints (119). The superficial and intermediate layers of the cervical muscles are known as prime movers, and are responsible for movement of the head and cervical spine (120). For a cross-sectional illustration of the cervical muscles refer to Figure 2.3.

Figure 2.3: Cross section of the cervical spine illustrating the deep segmental stabilizers and the superficial prime movers

2.5.3 Effect of neck pain on cervical musculature

If the cervical musculature can play a role in injury prevention, it is essential to understand the link between muscular weakness and injury or the primary symptoms of minor neck injuries, NP. Numerous studies have illustrated reduced strength and endurance capacity in the cervical extensor and flexor muscles in individuals with NP (121, 122). Falla et al. (67)
assessed the fatigue of the superficial flexors, sternocleidomastoid (SCM) and the anterior scalene (AS) muscles during sustained cervical flexion contractions at 25% and 50% of the maximal voluntary contraction (MVC) in patients with chronic NP. Individuals with NP manifested greater myoelectric fatigue in the SCM and AS muscles relative to the controls. Gogia and Sabbahi (123) similarly demonstrated greater cervical flexor muscle fatigue during low load sustained contractions (25 % MVC).

To examine the functional interplay between the deep cervical stabilizers and the superficial prime movers, Falla et al. (124) developed an electromyography (EMG) technique capable of measuring the activation levels of the deep cervical flexors. This technique was used to determine whether those reporting NP demonstrated different activation levels during performance of the cranio-cervical flexion (C-CF) test when compared with healthy controls (125). The study found that NP patients exhibited disturbances in the neck flexor synergy “where impairment in the deep muscles, important for segmental control and support, appeared to be compensated for by increased activity in the superficial muscles (SCM and AS)” (61).

Given that increased superficial cervical EMG activity has been identified in individuals with NP (69, 70), the neuromuscular efficiency (NME) of the SCM and AS muscles was also investigated. NME was defined as the quotient of force and the integrated EMG during a cervical flexion contraction at 25% and 50% of MVC (126). The authors found less NME for the SCM and AS when contracting at 25% MVC, but not at 50% MVC in individuals with NP when compared to healthy controls. The reduced NME at 25% MVC illustrates that individuals with NP required higher levels of muscular electrical activity to produce an equivalent low level force output, or conversely with a comparable level of electrical muscular activity, NP patients generated lower force outputs (125). In summary, individuals with NP demonstrate the following neuromuscular patterns: (a) greater fatigability of the superficial prime movers (61, 66, 67, 70, 78, 125); (b) impaired neuromuscular efficiency of the superficial prime movers (65, 67, 70, 78); and (c) impaired recruitment of the deep cervical flexors that appears to be compensated for by increased superficial muscle activity (61, 69, 124, 127, 128). Although these factors have not been examined in athletic populations, the high level of NP reported in rugby players (44) highlights the potential relevance of these results.
2.6 The Impact of Rugby Participation on the Cervical Spine

Injury surveillance studies have demonstrated that minor cervical injuries occur at a high frequency in collision sports such as rugby (20, 30, 36, 96). A neck injury surveillance study of 262 male amateur rugby players found that severe neck injuries during game play accounted for 6.7% of the total injuries sustained, while the majority (68%) were classified as minor (30). Despite the prevalence of minor neck injuries, research regarding the impacts of these injuries in collision sport is limited.

2.6.1 Pathological changes to the osteoligamentous system

Acute trauma to the cervical spine as a result of rugby participation is well researched (47, 83, 98). It has been reported that the presence of underlying cervical pathologies may increase the likelihood of sustaining a catastrophic neck injury (51, 129). However, the low frequency of catastrophic neck injuries and the inability to identify those most at risk, due to the lack and cost of screening of the cervical spine, makes it difficult to substantiate this claim (98). If minor cervical pathologies can potentially predispose or increase the risk of injury it is essential to understand the changes that occur in the cervical spine as a result of rugby participation.

Using magnetic resonance imaging (MRI) to view the cervical spines of senior front row rugby players aged 21-37, it was discovered that 66% had osterosclerosis of the vertebral bodies corresponding to Modic’s type II vertebral degeneration. These pathological changes were absent in age matched controls (83). This accelerated conversion of hemopoietic bone marrow in the cervical vertebrae into fibrous and sclerotic tissue is a consequence of the repeated microtrauma sustained in this region of the spine during rucking, mauling, scrumming, and tackling. In this same study, vertebral sclerosis was associated with the degeneration of the vertebral end plates in 77% of the senior (aged 20-37) and veteran players (aged 37-57). When comparing disc abnormalities between senior and veteran players, 48% of senior rugby players had protrusive discs and 29% had disc herniations. These figures rose to 71% and 36% respectively for veteran players, indicating that the presence of degenerative changes increases with the length of a player’s career. For both senior and veteran players MRI revealed: (a) decreases in vertebral body height with modifications in sagittal diameter; (b) 56% of the cervical discs contained some aspect of degeneration; and (c) 71% of the discs had lost at least 50% of their height (83).
In a recent study using functional MRI to examine the cervical spine of 206 professional French Rugby Union players, chronic lesions were observed across all positions. Analysis of the cervical canal diameter revealed that regardless of position 52.4% of players over the age of 21 had canal narrowing as indicated by their Torg index and canal-cord ratio (47). Research examining the location of lesions sustained during an acute catastrophic injury revealed that “the majority of cervical lesions [were] encountered … in the lower cervical spine, in the transition zone between the immobile thoracic spine and the mobile cervical spine” (83). Given the primary role musculature plays in stabilization of the cervical spine (115), damage and modification to the osteoligamentous system due to repetitive trauma could potentially indicate that: (a) cervical musculature strength/endurance is insufficiently prepared to cope with this repetitive loading; and/or (b) loading of the cervical spine occurs in positions (at the ends of ROM) where the cervical musculature is not able to contribute to stabilization, thus leaving the osteoligamentous system to fulfil this role.

### 2.6.2 Impairments to the neuromuscular system

In addition to documented changes in the osteoligamentous system of the cervical spine, studies have also shown impairments in cervical joint position sense (CJPS) in rugby players (44, 48, 51). The cervical muscles are unique in that they contain a high concentration of proprioceptors arranged in complex arrays. These proprioceptors, which are primarily muscle spindles, play two important roles: (a) they provide the central nervous system with sensory information regarding position and movement of the cervical spine; and (b) they initiate spinal reflexes that stimulate muscles to contract in order to stabilize and protect the cervical spine (51, 96). Factors such as pathological changes to the osteoligamentous system, trauma, muscle fatigue, and aging have been shown to impair CJPS performance (51, 96).

To explore the impact of amateur rugby participation, one study examined CJPS in left and right rotation over three trials. They reported CJPS errors, defined as an average combined mean for both directions exceeding 4.5°, in 33% of forwards and 35% of backs (44). Lark & McCarthy (48) examined CJPS in Flx, Ext, LtFlx, RtFlx, left and right rotation in semi-professional rugby players (n= 52) and trained athlete (non-rugby) controls (n= 15). The only significant difference in CJPS between the rugby players (mean error: 6°) and the controls (mean error: 3°) was observed for the extension movements (48). In comparison, a more recent study of CJPS in forwards (n= 10), backs (n= 10), and non-rugby playing elite athlete controls (n= 10) found similar repositioning errors in the forwards and backs. Rugby players
were less accurate and less consistent than the controls in the CJPS tasks. The authors reported that repositioning errors obtained for the rugby players were consistent with previous work with older adults (age > 65 yrs) and NP patients (51). These documented changes in CJPS in rugby players have the potential to impair players’ ability to initiate reflex contractions in the cervical musculature (51). In contact situations this impairment could potentially place them at greater risk of sustaining an injury, due to the large role the cervical musculature plays in stabilizing this region of the spine (115).

2.6.3 Cervical range of motion changes

Both forwards and backs have demonstrated active cervical ROM deficiencies (44). When rugby players were compared to active non-rugby playing controls, the results indicated that forwards have significantly less cervical ROM than both backs and controls. A correlation analysis indicated that decreased cervical ROM was positively correlated to the age of the player and the number of years played (48). A single game of rugby was found to reduce cervical ROM in elite rugby players (n= 21) for Flx, Ext, left (LtFlx), and right lateral flexion (RtFlx), left and right rotation, independent of player position (49). Further analysis for position concluded that backs had significantly reduced range in Flx, while forwards were more affected in Ext and LtFlx (49). In order to determine the cumulative effect over a season, Lark & McCarthy (50) examined 22 rugby players in the English Premiership league using pre-, mid- and post-season assessments. When player position was taken into account, backs had a greater absolute ROM in all directions over the three testing periods when compared with forwards. However, the percentage decline for overall ROM as measured during the post-season assessment was similar irrespective of player position (50). These findings suggest that rugby players present with impaired ROM and that this impairment is more pronounced the longer a player’s career extends and for those in the forwards.

2.6.4 Summary

Degenerative changes to the osteoligamentous system have been observed in front row forwards when compared to age-matched controls (83) and across all playing positions (47). For forwards these degenerative changes have been linked to participation in the scrum (31, 83) and have been found to increase with the age/career length of the players (83). However, the presence of pathological changes in the osteoligamentous system observed in both forwards and backs suggests a common mechanism such as participation in tackles, collisions
and/or rucks. With respect to measures of cervical function, impairments in CJPS and ROM have been observed in both forwards and backs, further supporting a common mechanism. Exploration of the CPJS impairments between rugby players and healthy controls has revealed varying results. With some reporting impairments for all examined directions (44, 51), and others reporting that the only difference in CJPS between rugby players and the controls was for Ext (48). In contrast, for cervical ROM decreases in ROM for both forwards and backs have been reported over a season (50) with forwards having larger impairments compared to backs and controls (48). In parallel with the severity of pathological changes to the osteoligamentous system cervical ROM has been found to decrease with the age/career length of the player (48).

### 2.7 Sequence of Prevention Model

In the sports injury literature, ‘Sequence of Prevention’ is a phrase that has been coined to describe measures taken to prevent injuries in sport (21). This ‘Sequence of Prevention’ consists of three Phases. Phase 1 encompasses injury surveillance, which must be conducted to identify and describe the extent of the examined sports injury problem. Phase 2 involves identification of factors and mechanisms that play a role or influence the occurrence of the observed sport injury. The third and final Phase involves the implementation or introduction of rule changes, equipment, injury prevention programs, or training protocols to reduce the future risk and/or severity of the sport injury, as guided by evidence from Phases 1 and 2. Once this third Phase has been implemented Phase 1 is repeated to evaluate the effects of the introduced measures (21). An example of the successful application of this ‘Sequence of Prevention’ is the use of the ‘head-up’ tackle in American football, which minimizes neck injuries through reductions in the frequency of impacts to the vertex of the head (130). In the early 1970s, the National Football Head and Neck Injury Registry compiled data regarding head and neck injuries and concluded that the majority of spinal injuries occurred as a result of axial loading to the head. The findings from this injury surveillance lead the National Collegiate Athletic Association and National Federation of High School Athletic Association to ban the use of ‘spear tackling’; the use of the vertex of the helmet as the initial point of contact when striking a player on the opposing team during a tackle or block. After the implementation of this rule change from 1976 through 1987, there was a dramatic decrease in the total number of cervical spine injuries sustained by both college and high school players.
(approximately 60% decrease over two years) (131). For an illustration of how this framework relates to the occurrence of neck injuries refer to Figure 2.4.

**Figure 2.4**: Outline of the ‘Sequence of Prevention’ model adapted to neck injuries and potential preventative measures

### Phase 1: Rugby neck injury surveillance data

Phase 1 should examine the frequency of injuries in sport (21). The physical nature of rugby implies that injuries are an inherent aspect of the game (11, 129). Rugby players are significantly more likely to sustain an injury to the cervical spine than the thoracic or lumbar regions (30). This highlights the vulnerability of the cervical spine, which functions as a mobile column, located between the bulk of the torso and the head. Injuries to this region of the spine were examined in twelve English premiership rugby clubs (546 players) over the course of two seasons, culminating in a total of 118 cervical injuries associated with 1608 days of training and play absence due to injury (30).

When examining neck injury surveillance data in rugby, the reported incidence ranges from 0.5 to 10.58 injuries/1000 player-hours for professional players (30, 46, 84), 2.9 injuries/1000 player-hours for amateur players (36), and 6.1 injuries/1000 player-hours for youth rugby
players (34). For professional forwards cervical nerve root injuries ranked 3rd in frequency (4.5 injuries/1000 player-hours) and concussions ranked 5th (4.0 injuries/1000 player-hours), while for backs concussions ranked 3rd in frequency (4.9 injuries/1000 player-hours) (11). The overall injury rate indicates that for professional players the head/neck region was the 2nd most frequently injured anatomical site (20). At the amateur and youth grades there have been fewer injury surveillances studies, with combined head and neck trauma accounting for 35% of all injuries at the amateur level (87) and minor neck injuries accounting for 30% of all injuries at the youth level (35). For youth rugby the head/neck region was the most frequently injured anatomical site (34). These findings showcase the high frequency of head and neck injuries in rugby and that the risk of these injuries increases with the level/grade of play (46). Thus professional players are at a higher risk of sustaining neck injuries and may benefit the most from prevention measures.

In a study examining cervical injury rates in 262 amateur rugby players, severe neck injuries (> 3 weeks missed play) during game play accounted for 6.7% of the total injuries sustained while minor injuries (< 1 week missed play) accounted for 68% (36). A similar pattern of injury severity has also been documented at the youth level (35, 87). At the professional level a study reported that of the 106 game play cervical injuries sustained over the season 27% were recurrent injuries (30). Further analysis revealed that both the average and median number of days missed following recurrent injuries were double that of new injuries (30).

A correlational analysis to determine whether a player characteristics (e.g. player’s age, stature, body mass and body mass index) were linked to the incidence and severity of spinal injuries sustained during game play, revealed no statistically significant correlations between injury rates and the examined variables. However, the incidence of spinal injuries was affected by the position of the player on the field, with forwards recording twice as many spinal injuries as the backs (30). A similar study investigating neck injury incidence in amateur rugby players reported that 78.9% of neck injuries affected forwards (36). Similar conclusions have been drawn by studies which examined playing position and the incidence of neck injury in rugby, with all reporting a higher incidence risk in forwards (20, 30, 36, 132, 133). Swain (2010) found that the hooker, prop, and back row positions were the players with the highest risk of neck injury, while the full-back, wingers, fly-halves, and centres were the least likely to sustain a neck injury (36). A case series analysis examining the distribution of neck injuries in rugby by position, found the hooker was the most frequently injured player.
followed by the props, who sustained 30% and 17% of the spinal injuries, respectively (27). During scrummaging, those players most at risk of sustaining a neck injury were the front row forwards (hooker and props). However, the highest overall risk of neck injury was recorded for back row forwards (number 8 and flankers) and was attributed to the tackle phase of play (30). The higher frequency of neck injuries in forwards may explain the observed impairments in cervical ROM when compared to backs (48) and is likely attributed to the forces experienced during the scrum. However, whether this decrease in cervical ROM is a result of the cervical injuries or a protective adaptation of this region of the spine to minimize injury is unknown.

A review of neck injury incidence and severity in rugby by Swain et al. (36) reported large confidence intervals in the current literature, due the use of numerous injury definitions and measures of injury severity. This prohibited statistical analysis of the relationship between neck injury severity and playing position, thus preventing the formulation of a hypothesis on this relationship. This conclusion is further supported by a study of amateur rugby in Australia, where no relationship between neck injury severity and playing position was found (36).

As previously stated the most frequently sustained injuries in rugby are minor non-catastrophic neck injuries. The most frequently cited symptom of non-catastrophic neck injuries is NP (2). A study by Gemmell et al. (2007) conducted over a four-week period, revealed that NP was reported by 83% of amateur forwards and 41% of amateur backs (44). This is substantially higher than the 10-20% of the general population reporting NP (134). The origin and precise pathophysiological mechanism(s) of NP are often obscure (2, 61, 64). Research suggests multifactorial origins, which include external psychosocial and physical loading factors, as well as the psychological and biological characteristics of each individual (2, 40).

2.7.2 Phase 2: Factors and mechanisms which influence neck injury occurrence

The next step in the ‘Sequence of Prevention’ framework is the examination of factors and mechanisms, which influence the occurrence of neck injuries in the sport of rugby, refer to Figure 2.4 (21). This requires examination of the phase of play where these neck injuries occur, kinematics of the head and neck and the neuromuscular response during the event, and the role these factors might play in the prevention and/or occurrence of these injuries.
2.7.2.1 Contact events during a rugby match

Historically the majority of rugby cervical spine injuries were sustained by the forwards and occurred during the scrum (27). In a review of 11 studies (between 1952-2000) examining the distribution of cervical spinal injuries in rugby by phase of play, the authors reported that that the scrum accounted for 40.1% of cervical injuries, the tackle 36.3% and the ruck and maul 17.8% (27). Current research indicates a change in this trend, where the tackle now plays a greater role in the total number of neck injuries than the scrum (24, 36, 100, 135, 136). These findings are further substantiated by Fuller et al. (30) who found that the tackle caused six times as many injuries (52% of all neck injuries) than other types of contact events (30). This implies that players of all positions are at risk of neck injury during the tackle. As both the rules and the style of play in rugby have evolved, the number of neck injuries attributed to the scrum has decreased while those sustained in the tackle have increased (27). Potential explanations for this change have been proposed in the literature and are listed as follows: (a) game intensity (137); (b) player fatigue (30, 137); (c) increased size, strength and speed of players; (d) rule changes on scrum engagement (27); (e) education of players and coaches (33, 138, 139); and (f) the increased amount of time the ball is in play during a game resulting in increased contact exposure time (140). However, these findings may reflect the frequency of the tackle event during the game (average of 221 events/game), rather than its propensity to cause injury. When the potential to cause injury is considered, collisions (70%) and scrums (60%) are more likely to result in injury than the tackle (100). This conclusion is further supported by injury surveillance work in English Premiership rugby where injury data was examined to explore the propensity of events to cause an injury. The authors reported that the scrum presented the highest propensity for injury with 8.1 injuries/1000 scrums, which was higher than any other contact events (100). Injury surveillance of junior and senior amateur rugby players in South Africa during the 2008-2011 seasons also found that scrums accounted for 42% of all acute catastrophic spinal cord injuries, despite there being far fewer scrums than tackles during a game (24).

Cervical injuries most frequently occur during open play with the tackle highlighted as the key mechanism of injury (26, 100). Fuller et al. (100) examined two seasons of rugby in 13 English Premiership Clubs and reported an average of 221 tackle events per game. At a professional level, each forward will make $11 \pm 7$ tackles per game while a back makes make $9 \pm 6$ (141). To date no evaluations have been undertaken to examine force vectors
experienced at the neck during a rugby tackle. A study using accelerometers to evaluate body loads during a rugby game demonstrated that a forward sustained 105 heavy impacts (7.0-7.9 Gz) and 10 severe impacts (>10.0 Gz), while a back was exposed to 54 heavy impacts and 13 severe (142). However, this study failed to identify the phase of play associated with these impact events, so it is not known whether these occurred during a tackle. This study reported that forwards spent 5.04 min and 1.09 min running in these speed zones 13.0-18.0 km/hr and 18.0-24 km/hr respectively, while backs spent 4.34 min and 1.32 min respectively (142). By combining this information with studies focusing on peak head acceleration during rear-end impacts in motor vehicle accidents, it is possible to predict forces when being tackled or tackling at the same speeds. The literature indicates that an impact velocity of 12 km/hr resulted in peak head accelerations of 8 Gz while speeds of 20 km/hr increased the linear head acceleration to 14 Gz (143). As players are sprinting at these speeds during a game, it is likely that their head will be exposed to similar acceleration values when tackles or collisions occur. Recent work with American gridiron players wearing helmets equipped with linear accelerometers has shown that the average head acceleration associated with impacts range from 21 to 32 Gz (144-147). Documentation of concussion-inducing impacts in Division I collegiate gridiron players has recorded linear acceleration values ranging from 56 to 169 Gz (144-147). Although the linear head acceleration values, and therefore the potential for injury seen in American gridiron would likely be higher than those achieved during an impact event in rugby, due to the lack of helmet and protective equipment in rugby, they provide some insight into the force vectors experienced during collisions.

Injury surveillance data has revealed that many injuries to the cervical spine in rugby can be linked to poor or incorrect technique in the contact phase of play (27, 56, 57, 148). High tackles, double tackles and the spear tackle have been identified as posing the greatest risk for cervical spine injury (27). Recently research examining the risk of injury related to scrummaging has reported that risk of injury is significantly high for collapsed scrum, 8.6 injuries/1000 scrum events, when compared to scrums that did not collapse, 4.1 injuries/1000 scrum events (149). In a neutral cervical posture the cervical spine has a lordotic curve, and the paravertebral musculature and the vertebral ligaments in the neck are able to dissipate the forces that are transferred to the head (115). When the neck is slightly flexed, which often occurs during a tackle, the cervical spine behaves as a segmented column with the vertebral bodies of the cervical spine lined up under another. An impact to the vertex of the head in this posture results in the transmission of the axial force along the spine’s longitudinal axis (axial
loading). A large amount of force is transferred to the cervical vertebrae, allowing for only minimal force dissipation by the musculature and ligamentous system of the cervical spine. In rugby, large axial forces can be applied to the vertex of an athlete’s head when they make contact with the ground or with another player. If these axial forces exceed the tensile strength of the cervical vertebrae they can cause the vertebral bodies to explode or fracture, driving bone chips into the spinal canal and endangering the spinal column (97, 150). Therefore, tackling with the head in a downward (flexed) position can greatly increase the risk of serious cervical spine injury (56). A detailed explanation of the potential injury mechanisms that can occur in rugby has been present by Sinbaldi et al. (57).

Research has demonstrated that during the scrum the necks of the front row players experience high levels of compression (151) and as a result these players are exposed to a high incidence of cervical facet joint injuries (30). Biomechanical evaluations of cervical spine injuries have established a relationship between the occurrence of facet joint injuries and the presence of osteoarthritis in the cervical spine (130). The degenerative changes seen in retired front row players support this hypothesis (83). The forces experienced by front row players in the scrum contribute to the occurrence of facet joint injuries in the cervical spine, which in turn potentially contribute to the development of degenerative changes documented in the cervical spine of these players later in life (30, 47, 83).

2.7.2.2 Kinematic examination of head and neck movement during injury

As concussions (brain injuries) are common injury events in collision sport, the current research focus for the head and neck region has been directed towards understanding the mechanisms and identifying potential avenues for concussion prevention (144-147, 152). Despite the high documented frequency of minor neck injuries (30, 35, 36) and the observed degenerative changes in the cervical region in rugby players (47, 51, 83), fewer studies have investigated the biomechanical or neuromuscular parameters surrounding neck injury due to direct head impact (152). Neck injury, and in broader terms, NP resulting from a loading event, represent a broad class of complex clinical problems (130). Acute injuries to this region occur as a result of two types of events: (a) head contact neck injuries where the head strikes a surface and the neck is required to either stop the moving torso or the neck is placed in tension by the head, and (b) non-head contact decelerations where the torso is restrained and the neck is required to stop the moving head (130). For head contact neck injuries, laboratory and cinematographic analysis using cadaver models has established that the
primary mechanism of neck injury is axial loading, disregarding the concomitant motion of the neck at impact (54, 130, 131, 153-155). In a review of catastrophic cervical injuries in rugby, the predominant injury was facet dislocations, in particular bilateral facet dislocations in the lower cervical region C4/5 and C5/6 (26). Based on this injury pattern, the authors proposed ‘buckling’ as the primary mechanism of injury, which occurs when the head makes contact with an object (another player or the ground) and a compressive force is applied along the spine (26).

The risk of neck injury depends on a number of factors including the constraints on head and/or neck motion during impact (which can prevent escape from the weight of the torso) and the orientation of the impact surface (130). Researchers and clinicians have proposed that the infrequent occurrence of catastrophic neck injuries following head impact can best be explained by the flexibility of this region of the spine (130, 154, 156). Nightingale et al. (155) found that the cervical spine could flex through more than 96° without sustaining injury. As a result of this flexibility, during most head impacts the neck is able to bend out of the path of the moving torso, thereby avoiding injury. Constraint of head/neck movement, which occurs when the head pockets into an impact surface (another player or the ground), and impairs the ability of the neck to escape the path of the moving torso, thereby increasing the risk of neck injury (130). In experimental cadaver studies buckling of the cervical vertebral column occurred rapidly (between 2 and 20 milliseconds (ms)) following application of forces with large compressive components (130, 153).

Non-contact injuries to the cervical spine such as whiplash injuries sustained during impact loading events from motor vehicle accidents or sporting participation are common injuries with at least one million cases reported in the United States each year (157). Laboratory simulation of these impact events used a 16.7 kg free falling mass strapped to the forehead of six hybrid cadaveric/surrogate models to produce an impact force of 504 N on the head. While a portion of this impact force was directed toward the production of rearward head acceleration of 5 Gz, the remaining force was transferred to the neck (205 N) and converted to posterior shear. The authors argued that during real-life situations the portion of neck shear force absorbed by the cervical muscles is likely very small, particularly in situations where the individual is unprepared for impact or when they have failed to brace their neck musculature prior to the impact in order to minimize injurious spinal motions (152).
2.7.2.3 Neuromuscular response of the cervical musculature to impact events

Little is understood with regards to the role of the cervical musculature during impact events. Instead previous work has focused on kinematic data from the head and neck (130, 157, 158). This despite the fact that cervical musculature is primarily responsible for the spatial position and active motion of the head (86, 157). During an impact event in a seated position the initial body movements are the forward translation of the torso and the production of an S-shaped cervical spine curve. This S-shaped curve in the cervical spine forces muscles in this region into an elongated position, which stimulates the respective stretch receptors. This stimulation results in an eccentric reflex contraction in the affected cervical muscles, which occurs approximately 180 ms post-impact (157). Work with hybrid cadaveric/surrogate models has documented peak head posterior shear force and rearward acceleration within 60 ms of the 504 N impact. This precedes the reflex contraction in the affected musculature suggesting little reflex protection to this region of the spine during the impact event (152). During impact events where the neck musculature is relaxed and the applied force on the neck exceeds the structural integrity of the osteoligamentous system, it is unlikely that the cervical musculature will play any role in injury prevention/minimization.

Research examining impact loading of the head has proposed that the SCM and the upper trapezius are the primary dynamic stabilizers of the head and neck region (89-91, 157). These authors state that during impact events the muscle onset time and the level of contraction produced “likely attenuate head acceleration and/or absorb energy from direct and indirect impacts”(90). Exploration of kinematic and neuromuscular responses during low velocity impacts in healthy volunteers reported that head movements begin approximately 60 ms after impact and continue until 400 ms post-impact (158, 159). The onset of muscle contraction occurs approximately 120 ms after impact (157, 159). Other research examining the cervical muscular response to simulated forward horizontal perturbation (peak acceleration 1.5 Gz) reported muscle onset times of 82 ± 11 ms in the masseter, 74 ± 5 ms in the SCM and 82 ± 7 ms in the cervical paraspinals (158). Despite the discrepancies between muscle onset timing in these studies, movement of the head precedes contraction of the cervical musculature after impulsive loading events. Examination of the individual cervical musculature reaction time response has demonstrated that the levator scapulae, SCM and the trapezius muscle have the most rapid muscle onset response during impact, while the semispinalis and splenius capitis muscles are more delayed in their response (157, 159, 160). Although muscle onset is
delayed relative to the occurrence of head movement, research has reported that onset time precedes peak head acceleration (157, 159, 160). From an injury reduction perspective improved strength and neuromuscular coordination in these key muscles (levator scapulae, SCM and upper trapezius) may result in enhanced dynamic stabilization of the head-neck segment during impact, which in turn may translate into a reduction in the frequency or minimization of the severity of minor cervical injuries.

Kumar et al. (157) have shown that the acceleration and direction of impact determines which muscles respond and the level of muscular activation. As the acceleration of the impact is increased the mean muscle onset time is reduced in both forward and rear impacts. For example when a frontal impact is unexpected, the mean onset muscle time for the left trapezius decreases from 166 ± 24 ms for impacts with an acceleration of 4.9 m/s^2 to 112 ± 25 ms for impacts of 14.0 m/s^2 (157). The muscle primarily loaded during rear impacts is the SCM. Research has documented contraction levels of 179% in the left SCM and 140% in the right SCM in unexpected conditions at acceleration speeds of 13.7 m/s2. For these same conditions, examination of the % MVC in the splenius capitis and the trapezius reveals contraction levels did not exceed 35% of MVC for either muscle. In contrast, frontal impacts primarily load the trapezius muscle. However, for the same accelerations, the maximum activity in the trapezius ranged from 38-79% MVC indicating that similar loads place less stress on the trapezius muscle. During the frontal impacts the activation level of the SCM (less than 30% MVC) was similar to that seen in the trapezius and splenius capitis during rear impacts (157). Although these findings were all conducted in a seated position to simulate impact situations in a vehicle, they provide some guidance regarding the muscle activation levels and onset times that could be expected during contact situations in sports, in particular the whiplash associated with being tackled.

Siegmund et al. (158) examined the role that prior knowledge of the impact event and the timing of the whiplash-like perturbation had on the onset and amplitude of the neck muscle response, and the peak magnitude of head and neck kinematics in seated healthy participants. In this study participants were randomized into three different conditions: (a) a countdown for participants who were alerted to their perturbation (alerted), (b) a perturbation without alert for participants who expected it within 60 s (unalerted), and (c) an unexpected perturbation for surprised participants who were deceived (surprised). The findings revealed that event awareness affected the timing of the neck muscle response, where activation of the
SCM and the cervical paraspinal muscles occurred earlier in the alerted and unalerted participants than the surprised. A potential explanation for this occurrence could be changes in the membrane potential of the sensory neurons due to enhanced selective attention. Another possible explanation is modifications of neural recruitment patterns of the alpha motor neurons resulting from motor preparation in the alerted and unaltered groups (158, 161). The sensorimotor systems of the participant in the surprised condition were not similarly prepared; therefore, neck muscle activation in these individuals was delayed. When only the male participant’s data were examined, peak angular accelerations were greater in the surprised group when compared to the alerted and unaltered groups. The authors attributed these larger values to a modified motor behaviour strategy employed by the surprised males to compensate for the delayed muscle onset. The surprised male participants increased the magnitude of the reflex activation in the SCM and cervical paraspinal muscles; thereby increasing the stiffness of the head-neck segment which resulted in greater peak angular acceleration values (158). In summary, awareness of the impact decreased cervical muscle onset time and in males resulted in lower angular head acceleration values. The findings from this study could suggest that contraction of the cervical musculature prior to impact may reduce the frequency and/or severity of the neck injury.

Research examining gender differences relating to dynamic stabilization of the head-neck region in response to an external force application reported greater head-neck angular acceleration in female participants. The authors attributed this finding to decreased levels of cervical strength (50% less than males), neck girth and head mass in the female participants. These factors resulted in reduced head-neck segment stiffness during the impact events when compared to males (92). To further examine the role neck girth and strength may have on injury tolerance, the National Football League (American gridiron) adjusted the NS of test dummies to simulate varying levels of cervical strength and neck girth. Reconstruction of impact events revealed that increased NS improved injury tolerance by up to 35% (162). However, research examining the role of isometric cervical strength and its relationship to kinematic data of the head and neck region during impact in sports has provided evidence to the contrary (90, 91, 147). Head impact biomechanics was evaluated throughout a season in 37 youth ice hockey players using helmets equipped with accelerometers. No relationships were found between isometric cervical strength and either linear or rotational acceleration during impact, which contradicts the notion that the cervical musculature mitigates head impact acceleration (147). Other studies have examined the impact of an eight-week neck-
specific intervention programme on dynamic head-neck segment stabilization in soccer (91) and American gridiron players (90). Although both studies reported varying results with respect to improvements in cervical strength over the eight-week period, neither observed any change in dynamic stabilization of the head-neck region (90, 91). A study assessing the effect of neck strength imbalances and the role this played in head acceleration during a soccer-heading task, reported that the mean strength difference between the cervical flexors and extensors was positively correlated with angular head acceleration during a low velocity-heading task, with a trend towards a significant positive correlation for linear head acceleration (89). These findings suggest that the balance between the agonist and antagonist neck muscle groups may play a larger role in improving dynamic neck stabilization than improving peak force production.

2.8 Summary of Neck Musculature and its Role in the Occurrence of Neck Injuries

In summary, the risk of minor neck injuries in collision sports is relatively high when compared to catastrophic neck injuries (30, 36). In addition, injury surveillance data indicates that once an injury has occurred, the injured player is more likely to sustain another injury to this region (30, 36). Referring to the ‘Sequence of Prevention’ model; Phase 1 entails an examination of the frequency of injuries while Phase 2 requires the investigation and documentation of factors or mechanisms, which may influence the observed frequency of injury (21). For the purpose of this thesis the focus is specifically on the role of the cervical musculature. As previously highlighted, the cervical muscles may play a role in dampening peak head acceleration during impact situations, which may minimize or reduce the frequency of minor neck injuries. As the neck musculature also stabilizes neutral and slightly deviated postures (61, 115, 120), it may provide a pathway to reduce or mitigate these injuries. The question then becomes: what can be done to improve neck muscle strength and control?

As a functional measure of minor neck injuries which may go un-reported during a rugby season, the research pathway this thesis will examine is the frequency and severity of self-reported NP and NS in rugby players. Cervical musculature peak force has commonly been used as an indicator of neck muscle dysfunction (58, 163) with a number of studies using a variety of populations reporting strength decrements in individuals with NP (6, 40, 65). In
contrast, no subsequent reductions in NP have been shown in studies where neck specific interventions have produced documented improvements in force (72). Given the conflicting evidence, there is a lack of consensus among clinicians and researchers with regard to the correlation between NP and neck strength measurements. In comparison to research examining neck strength, fewer studies have focused on neck muscular endurance (58, 163). The few that have, reported higher variability within this measure due to factors that modulate the performance of sustained contractions, such as motivation and muscular fatigue (59). Despite these factors, impaired endurance capacity and reduced neuromuscular efficiency of the cervical musculature is a commonly reported finding in patients with NP (64, 163, 164). Generally, little consensus among clinicians and researchers exists with regards to the correlation between NP and neck strength and endurance. However, researchers appear to agree on the use of these variables to determine training dosage and document rehabilitation efficacy (58, 165). The issues and criteria for the comprehensive assessment of neck strength and endurance in rugby are summarized in Table 2.1.
## Table 2.1: Issues and criteria for the comprehensive assessment of neck strength and endurance in rugby players

<table>
<thead>
<tr>
<th>Possible Explanation</th>
<th>Research</th>
<th>Comparable research findings in other populations</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Changes that occur over a season</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>↓ cervical ROM for backs and forwards</td>
<td>• Modifications to osteoligamentous system</td>
<td>• Examined over season and game (49, 50) using a cross-sectional study (44) and a case-control (48)</td>
<td></td>
</tr>
<tr>
<td>↑ changes to the osteoligamentous system</td>
<td>• Forwards - repetitive loading from the scrum • All positions - the acute impulsive loading from the tackle phase of play</td>
<td>• Front row players ages 21-37 66% had osteosclerosis (83) • Increase in the number of protrusive discs and herniations as front row players age (83) • Of the 12 players examined across all positions 50% had cervical abnormalities (47)</td>
<td>• Rule changes for scrum and tackling laws • Teaching proper technique for tackling and scrummaging • Examine the role of the cervical musculature to enhance cervical stabilization and potentially reduce impact on osteoligamentous system</td>
</tr>
<tr>
<td>↓ CJPS for backs and forwards</td>
<td>• Muscle fatigue • Modifications to osteoligamentous system • Trauma</td>
<td>• Examined over a single training session (51) in a cross-sectional (44, 51)</td>
<td>• Similar findings have been reported in adults &gt;65 years and neck pain patients • Examine CJPS • Assess cervical musculature endurance • Document trauma to neck region during season</td>
</tr>
<tr>
<td>↑ neck pain (43% in backs and 83% in forwards)</td>
<td>• Acute trauma due to incident • Accumulation of micro trauma from repeated loading of cervical spine</td>
<td>• Examined in a single observation study over a 4 week period (44)</td>
<td>• Pain values substantially higher than reported in general population • Examine neck pain scores over a season and in players of differing career lengths</td>
</tr>
</tbody>
</table>
### Risk of cervical injuries over a season

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>Explanation</th>
<th>Literature Reference(s)</th>
<th>Additional Information</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>↑ injuries as the season progresses</strong></td>
<td>• Loss of cervical strength and endurance as season progresses</td>
<td>(30)</td>
<td>Evaluate cervical strength and endurance over a season</td>
</tr>
<tr>
<td></td>
<td>• Accumulation of micro-trauma potentially increasing risk of sustaining future neck injuries</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>↑ injuries during the 2nd half a match</strong></td>
<td>• Cervical musculature fatigues as match progresses</td>
<td>(30, 87)</td>
<td>Evaluate cervical strength before and after a game</td>
</tr>
<tr>
<td><strong>↑ injuries during match play</strong></td>
<td>• Speed and force during contact situations in match play is higher than training</td>
<td>(24, 30, 36)</td>
<td>Examine correlations between neck strength and neck injury data to establish trends</td>
</tr>
<tr>
<td><strong>Most injuries occur during the tackle</strong></td>
<td>• Acute trauma</td>
<td></td>
<td>Examine correlations between neck strength and neck injury data to establish trends</td>
</tr>
<tr>
<td></td>
<td>• Neck injury can be isolated to a single impulse event</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>↑ with the grade of play</strong></td>
<td>• Positive correlations have been found between neck peak force and occurrence of neck pain/injury in fighter pilots</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2.9 Assessment of Cervical Neck Strength and Endurance

Neck muscle strength and endurance have been assessed in both clinical and laboratory settings in a wide range of populations (58, 59). A number of definitions have been used to describe strength. For the purposes of this dissertation the following definition of neck strength has been selected: “the maximum force that muscles can exert isometrically in a single voluntary contraction” (59). Neck endurance is defined as the ability to sustain submaximal contractions repeatedly or to generate force over a given period of time (59). Neck muscle strength and endurance are commonly used as indicators of neck muscle dysfunction with a number of studies demonstrating reduced peak force, endurance capacity, and neuromuscular efficiency in individuals with chronic NP, whiplash, headaches and other neck/shoulder disorders (59). The physical properties of neck musculature (size and diameter) can be assessed using different imaging techniques such as MRI, computer tomography, ultrasound, and EMG. Neuromuscular evaluation of the cervical musculature is relatively easy for the superficial prime movers; however, access to the deep and intermediate muscles is difficult and in some cases not possible (58). From a clinical and rehabilitative perspective, the parameters of interest relate to the mechanical expression of neck muscle function. This is reflected in the ability of musculature in this region to generate peak force or to sustain submaximal loads for extended periods (58). In a review of the methods and clinical implications of cervical muscle strength testing, Dvir and Prushansky (58) state that quantitative assessment of cervical muscle strength may be of relevance in the following situations:

1. Trauma with no evidence of cervical spine instability
2. Diseases or disorders
3. Relating to posture or ergonomic factors
4. Relating to sport participation
5. To assess neck functional status of patients/participants
6. To assess progress over the course of a rehabilitation intervention

2.9.1 Methodological considerations for neck strength and endurance assessment

The complex anatomy of the muscular and osteoligamentous systems of the cervical region means direct quantification of individual muscle forces or moment arms
impossible (58). Most investigations are limited to gross estimations of the relative contributions of deep, intermediate, and superficial cervical muscles to the generation of peak force and endurance in a direction-specific manner (58, 120). Neck strength and endurance are typically assessed in 6 directions of primary motion, namely: Ext, Flx, LtFlx and RtFlx, and left and right rotation (58, 59, 166, 167). In this direction-specific manner, strength and endurance are evaluated either dynamically using isokinetic dynamometry, or statically using isometric contractions. For an illustration of the advantages and disadvantages of each mode of assessment are presented in Figure 2.5. An isokinetic assessment of cervical strength examines the ability of the cervical muscles to produce torque (force times the perpendicular distance between the line of action of the force and the axis of rotation) (59). The problem with this form of assessment is that the cervical spine consists of seven vertebrae and movements in the frontal or sagittal planes incorporates movements at each of these intervertebral joints. With no fixed axis of rotation there is “bound to be a misalignment between the mechanical (fixed) axis and the biological instantaneous axis of rotation” (58). Due to the technological issues surrounding assessment of torque in this region, the cervical musculature is primarily evaluated isometrically (58, 59). Assessment of isometric cervical strength and endurance mirrors the physiological demands placed on these muscles during daily activities (39, 168). These muscles are required to maintain static low-level isometric contractions to support the head during activities such as sitting and standing (39, 58). To isometrically assess the cervical musculature there are a number of assessment options available (58, 59). These are discussed in the following sections.
2.9.2 Methods of isometric assessment

The three most commonly used methods of isometric cervical strength assessment are: (a) manual muscle testing, (b) handheld dynamometry and (c) fixed frame dynamometry. In addition to these methods of isometric assessment, cervical strength and endurance results are also influenced by other methodological factors such as time of day, use of warm-up, the number of reps and sets during the experimental protocol, and the position of the neck and body during testing. A complete summary of the methodological considerations regarding the assessment of neck strength and endurance assessment is illustrated in Figure 2.6.
Figure 2.6: Summary for the methodological considerations for neck strength and endurance testing
Manual muscle testing. Manual muscle testing is the method most often used in a clinical setting due to the low cost and time requirement (59). This method requires the participant to assume a supine position for Flx and left and right rotation, a prone position for Ext, and seated for LtFlx and RtFlx. The neck strength is scored by the assessor on a five-point scale with a grade three score being equivalent to resisting gravity. Low levels of reliability and validity are found when grading individuals who exceed a score of three. For this reason manual muscle testing is not recommended as a means of evaluating cervical strength that ranks above a grade three (58).

Handheld dynamometry. Handheld dynamometry uses a device with a load cell interfaced between the examiner and participant. When measuring the strength of the neck musculature the device is held by the examiner and placed against, or strapped to the participants’ head. While the participant performs an isometric contraction, the examiner provides resistive force and proximal stabilization for contractions that are either participant initiated or examiner initiated (169, 170). Although this form of assessment allows the examiner to quantitatively assess cervical peak force, its reliability and validity are vulnerable to the strength of the examiner, position of the examiner, neck position and the ability of the examiner to stabilize the participant (169).

Fixed frame dynamometry. In the scientific literature the most commonly used method of cervical strength evaluation is the fixed frame dynamometry (59). This technique does not rely on the examiner for proximal stabilization or force application. In fixed frame dynamometry the load cell is attached to a fixed base, either a wall or frame, which is adjustable in order to accommodate individuals of different sizes. A seated position is the most common testing position, where the load cell unit is placed or strapped against the occipital, temporal and frontal regions of the head to assess Ext, LtFlx, RtFlx and Flx respectively (58). To minimize contributions from accessory muscles and other body regions, and to provide proximal stabilization, pelvic and torso belts (165, 166, 171) or 4-point safety harnesses (6, 172) are commonly used. To minimize contributions from the legs, researchers instruct participants to lift their feet off the floor (167) or place them atop a cardboard box (95). Two commercially available fixed frame devices area available, but the majority of research in this area is conducted using custom made devices (58, 59). Although the validity of this mode of
assessment is greater than the two previous forms of assessment, the differences in devices and protocols have produced a wide range of normative data, this impairs the ability to make valid clinical inferences (58).

2.9.2.1.1 Neck position during fixed frame dynamometry testing

Biomechanical modelling of the neck has shown that the majority of the cervical muscles are able to maintain at least 80% of their peak force generation capacity through the full ROM. However, the majority of research has reported maximal force generation in a neutral cervical position (59, 171, 173). A benefit of using a neutral position is that the risk of injury during maximal contraction is minimized (174). When evaluating rugby players who may be at an increased risk of injury due to stenosis of the cervical spinal canal or other undetected pathological changes (47, 83), these factors warrant consideration. Suryanarayana et al. (175) examined peak force in Flx and Ext for neutral and postures at 25%, 50%, and 75% of cervical ROM through the sagittal plane. A decrease in peak force was observed as the neck was deviated from neutral, with a force of 45.1 N reported while the neck was in a neutral position and 27.3 N at 75% ROM (approximately 52°) for Ext. A similar trend was seen in Flx where the peak force decreased from 31.4 N in neutral to 12.4 N at 75% ROM. In contrast, work by Chiu et al. (171) on healthy volunteers, reported that maximal isometric peak force for both Ext and Flx was obtained at 20° for males and 40° for females. These discrepancies in peak forces between studies could be attributed to the different testing apparatuses and experimental protocols employed.

2.9.2.1.2 Body position during fixed frame dynamometry testing

Another factor that could influence the magnitude of peak force is the position of the individual during testing (58, 59). Neck strength and endurance have been examined primarily in the seated position (6, 43, 75, 76, 88, 95, 166, 172, 176-178); however, research has also been conducted using supine (67, 179, 180), prone (163) and standing positions (165). As the occurrence of NP has been link to prolonged sitting, global assessments of peak force production for the cervical musculature have primarily been conducted in the seated position (6, 40, 42, 61, 181). In contrast, assessment of the deep cervical flexors using submaximal contractions and low load endurance trials has primarily been conducted in the supine position (65, 125, 182, 183). This is likely, due
to methodological considerations and the ease of locating the deep neck flexors in the supine position.

The differences in experimental protocols, testing equipment, body positions, and definitions of neutral cervical posture make comparisons between studies difficult. A study by Strimpakos et al. (165) examining the effect of body position on cervical force production assessed the reliability of peak force measures of neck strength in both seated and standing positions. Although the interclass correlation coefficients (ICC) for both positions over the three testing sessions ranked from good to excellent (0.84-0.96), the seated peak force results for Ext, Flx, LtFlx, and RtFlx were all significantly higher than the standing values. The authors attributed this finding to improved trunk stabilization in the seated position and increased compensation from synergistic muscles and other body segments (trunk and legs). No difference between left and right rotation strength were observed between the seated and standing position (165). The only other study to compare testing positions examined cervical Ext strength in seated and prone positions. The authors reported significantly greater peak force values in the prone position when compared to seated (184). One explanation for this difference was the use of a footstool to minimize contributions from the legs to cervical Ext peak force during the seated experiment. This aside, the peak force values in this study were substantially lower than other published values for both seated and prone positions, raising questions regarding the results. The comparison of cervical strength between studies is difficult due to the lack of standardization between experimental protocols and testing positions. In general, the greater the contribution from accessory muscle or compensation from other body regions, the greater the expected peak force recorded from the neck musculature,

2.9.2.1.3 Other methodological considerations for fixed frame dynamometry testing

Research has shown that isometric peak force and neuromuscular efficiency during submaximal endurance trials are subject to diurnal variations (185-187). Wyse et al. (187) evaluated Flx and Ext peak torque values during single leg isokinetic testing at three different time periods throughout the day (0800-0900 hrs; 1300-1400 hrs; and 1800-1930 hrs). Significantly larger peak torque values were obtained later in the day during the 1800-1930hrs session. Based on these results the authors recommended
that when evaluating leg muscle peak torque that diurnal patterns should be considered. For maximum peak torque values a testing time between 1800-1930 hrs was recommended, and the suggestion made that repeated evaluations should be conducted within the same 30 min timeframe on separate days (187). Similar diurnal trends have been observed for leg and back strength, where smaller strength values were recorded in the morning (188). To date, no research has examined diurnal strength variations in the cervical musculature. However, the general consensus is that repeated neck strength and endurance measurements should take place at the same time of day to eliminate this potentially confounding variable (59).

Inclusion of a warm-up prior to strength or endurance evaluation of a muscle group has been reported to not only have positive physiological benefits, but may also enhance participant acclimation resulting in improved performance (59). The primary beneficial effects of the warm-up have been attributed to temperature-related mechanisms such as: decreased resistance of muscles and joints, greater release of oxygen from haemoglobin and myoglobin, increased metabolic reaction times, enhanced nerve conduction rate, and increased thermoregulatory strain. The non-temperature related mechanisms have been listed as: increased blood flow to muscle, elevation of baseline oxygen consumption, post-activation potentiation, psychological effects, and increased preparedness (189, 190). A review reported that “active warm-up appears to improve both long-term (≥ 5 min) and intermediate performance (> 10 s, but < 5 min) if it allows the athlete to begin in a relatively non-fatigued state” (189). It appears there has been no research on the effect of a warm-up on neck muscle performance, although it has been suggested that neck specific warm-ups should be performed prior to neck testing to eliminate fear and increase participant confidence (59, 63).

2.10 Examination of Cervical Strength using Fixed Frame Dynamometry

Knowledge of normative peak force values for the cervical musculature is required in order to effectively design experimental protocols or execute rehabilitation programs. The maximal peak force values reported in the cervical musculature demonstrate high variability (58, 59). Some consistencies are evident though; cervical extensors consistently test significantly stronger than the flexors and lateral flexors (58, 59, 95,
165, 167, 171, 175). This phenomenon can be linked to the larger cross-sectional area of the cervical extensors, and to the larger metabolic demand placed on these muscles during daily activities (175). During standing, the centre of gravity of the head is located anteriorly to the transverse axis of the cervical thoracic vertebral junction and this in turn necessitates continual low level activation of the extensors to prevent the head from falling forward (39). The difference between peak force values in Ext and Flx is illustrated by a study that examined neck strength in physically fit males reported an average peak force of 253.2 N for Ext and 149.7 N for Flx (95). Unlike other body regions where comparisons can be made with the uninvolved extremity, this is not possible for the cervical spine. Rather, clinical cervical strength evaluation necessitates population specific normative data from repeated assessments to use as a basis for comparisons or to guide clinical decisions (58). When the lateral flexors were compared to cervical flexors the peak force values for these two directions have been reported to be within 10% of each other (95, 191). Previous normative data for seated neck strength assessment supports a trend of higher RtFlx strength for right-handed individuals (171). Despite this handedness pattern, strength assessment in LtFlx or RtFlx is often used as a reference point for potential deficiencies in the affected side (58).

2.10.1 Gender neck strength differences

The cervical musculature displays a significant gender effect, which is consistent with gender strength assessments in other regions of the body (167, 171, 175). The impact gender has on cervical peak force while in a seated position has been explored. For all directions males tested significantly stronger than their female counterparts, with peak force values varying between 20-70% (171), 42-58% (165) and 30-40%, depending on the study (166). To determine whether or not the gender effect was consistent across the different directions, Flx:Ext ratios have been examined for both males and females with ratios of 1:1.38 and 1:0.79, respectively reported (167). Kumar et al. (167) stated that the observed Flx:Ext ratios indicated that female participants were proportionally stronger in extension but weaker in flexion than the males. In contrast to those findings, a study examining a total sample of 93 healthy males and females grouped into age categories of 20-40, 41-60, and ≥61 years, reported that the Flx:Ext ratio approximated 1:1.67 for both genders and remained constant across all age groups (166).
2.10.2 Changes in neck strength as a function of age

The changes that occur in neck strength as a function of age are relatively inconclusive (58). One study has documented significant decreases for Ext and Flx peak torque values for males between the ages of 20-40 and those 41-60 and older than 61. However, no changes in strength were observed between the two older groups. In the same study females demonstrated a slightly different trend whereby the youngest group tested significantly stronger than the two older groups, and the middle age group tested stronger than those over 61 (166). Further support for the decline in neck strength as a function of age in males was found in an examination of maximal isometric strength in the flexors and extensors. Conversely, this decline was not observed in the females who maintained their strength levels into their seventh decade (192). In contrast Chiu et al. (171) found no significant decreases in strength across age groups (19-39, 40-59, and 60-84 yrs) in either males or females. These results are consistent with the findings of Jordan et al. (192) which demonstrated that participants maintained good levels of isometric neck strength in Flx, Ext, LtFlx, RtFlx, protraction and retraction until their seventh decade. These contrary findings can most likely be attributed to the different modes of assessment and experimental protocols.

2.10.3 Relationships between neck strength and other anthropometric variables

One of the inherent problems with the examination of physiological parameters such as strength and endurance is the existence of size-induced variation, where in general, larger individuals tend to test stronger than smaller individuals (4). To analyse the results of studies with participants of different sizes, researchers typically normalize the peak force values to an anthropometric value that is correlated to force production (4). Research examining muscle strength in the upper and lower extremities has reported that peak force values were correlated to body mass/weight of the participants. These values were then used to normalize the data to enable comparisons between individuals of different body masses (4, 193). In a recent study examining age-related differences in the neck strength of male adolescent rugby players it was reported that Ext peak force was correlated with age, height, and weight of the players (75). Cervical strength and body weight have demonstrated high positive correlations in athletes ($r=0.80$)(194), however in the general population the relationship between neck strength and body weight is weaker (males: $r=0.04-0.35$; females: $r=0.02-0.41$) (171).
Additionally, positive correlations have been reported between neck musculature peak force, weight (166, 167) and height (166, 192) for untrained male participants. Conversely, a negative correlation was recorded between age and peak force in males (167).

For females these neck strength relationships tends to vary with positive correlations reported for peak force and height (166), and negative correlations reported for both age, weight and peak force (167). In contrast, a study utilising healthy men and women \( (n= 91, \text{ages 20-84 years}) \) found no correlations between Flx, Ext, LtFlx and RtFlx and height and weight (171). Suryanarayana et al. (175) also found no correlation between anthropometric measures and isometric cervical strength using different ranges of Flx and Ext, which lends further support to this finding. These conflicting correlational findings may be attributed to the different modes of assessment, experimental protocols, and populations studied. This lack of consensus necessitates additional research with different populations to clarify the relationships between anthropometric variables and cervical peak force values.

### 2.11 An Examination of Cervical Musculature Endurance

The primary role of the cervical musculature is to support and stabilise the vertebrae in neutral and mid-range postures (174). Thus, the onset of NP is often associated with sustained static loading of the cervical spine (59, 67, 78). This highlights muscle fatigue in this region as a potential risk factor in the occurrence of muscle injuries and or the onset of pain (61, 64, 195, 196). Although neck strength and endurance are measured as separate factors there is a strong correlation between the two variables (59). However, the number of studies examining the endurance capacity of the cervical musculature is substantially lower than those that have examined peak force in this region.

The muscles of the cervical spine function differently from muscles in other regions of the body (58). Positioning and maintenance of the lordotic curve during standing posture requires very low-level submaximal contractions of the cervical musculature, albeit with a high degree of precision (39). Dvir and Prushansky (58) state “the reduction in force output following repetitive contractions, which is the typical sign of fatigue in the extremities or lumbar muscles, is probably not a characteristic of the cervical muscles” (58). This makes analysis and interpretation of the data collected
while evaluating endurance properties of the cervical musculature more difficult. Despite these obstacles, impaired neuromuscular efficiency and recruitment patterns in the deep and superficial cervical muscles during sustained submaximal contractions have been observed in individuals with NP (61, 67, 70, 78, 114, 120, 124, 125, 128, 172, 180, 197).

The endurance capacity of a muscle is reflected in its ability to sustain submaximal loads repetitively or continuously for a given period of time (59). Given this definition of endurance, time to fatigue (TTF) of a muscle or muscle group is inversely related to the work load requirements: the greater the % MVC load the less time the contraction is maintained (59). Previous work has shown that for a load of 100% MVC, the TTF is well under one minute. If a true MVC is obtained, this value should be closer to one second (198). A number of neuromuscular parameters play a role in the maintenance of a muscular contraction, including information processing in the central nervous system, muscle activation via the alpha motor neuron, release of calcium by the sarcoplasmic reticulum, and cross-bridge formation by the actin and myosin filaments (60, 64). In addition to these neuromuscular parameters, endurance capacity is also influenced by participants’ motivation, the neural strategy employed for muscle contraction, the intensity and duration of the task, the speed of contraction, and the type of contraction used (60, 64). Thus, when evaluating cervical muscular endurance capacity there are a number of physical and psychological factors that may influence the reliability of this measure.

2.11.1 Methods of evaluating cervical musculature endurance

In general there are three different ways to evaluate the endurance capacity of the cervical musculature: a) subjective scales, b) EMG analysis, and c) time-dependent methods. Although these assessment tools all provide objective measures of endurance they are inherently subjective as they are dependent upon a participants’ motivation during the task (attainment of MVC or maintenance of a submaximal contraction). Additionally, endurance trials using a submaximal load based on MVC may provide a false estimate of fatigue if true MVC was not obtained (59).

Subjective scales. The most commonly used subjective scale in sports and particularly exercise testing is the Borg Rating of Perceived Exertion (RPE) Scale which estimates
an individuals’ level of perceived effort (59, 199-202). The scale, first introduced by Dr. Gunnar Borg in the 1970’s, rates exertion on a scale of 6-20 and is a tool for estimating effort and exertion, breathlessness, and fatigue during physical work (199). Another scale, the Borg Category-Ratio (CR) 10 Scale, is also used. The CR10 is a general intensity scale for most subjective magnitudes with special anchors that can be used to measure exertion and pain. The CR10 Scale has previously been used as a subjective assessment of fatigue in several studies concerning the lumbar or cervical spine (5, 68, 175, 200, 202). Often this method is used in conjunction with EMG or time-dependent assessments as a subjective measure of a participants’ level of exertion (5, 77, 172, 201-204). Few studies have correlated the subjective ratings of exertion with more objective measures such as EMG values (175, 200). As indicated by Strimpakos (59), the simplicity of this mode of assessment makes it appealing and it provides some indication of the level of effort expended by each participant. However, the ability to extrapolate from these results is limited as each participant has different perceptions of their own effort (201).

**EMG analysis.** EMG analysis of cervical muscle activity is not as common as strength or endurance assessment of the thoracic and lumbar region (59). This may be due to the difficulty associated with accessing the deep and intermediate layers of the cervical musculature with EMG probes (intramuscular EMG), or in isolating signals from individual superficial cervical muscles (surface EMG). Currently there is little consensus among researchers regarding the reliability of EMG measurements in this region of the spine (59, 61, 67, 123, 183, 205-207). Despite this, research has demonstrated the practical relevance of EMG assessment in both clinical and research settings to differentiate those with NP from pain free controls (2, 5, 61, 68, 78, 121, 122). As highlighted previously, EMG analysis has identified the following neuromuscular patterns in individuals with NP: (a) greater fatigability of the superficial prime movers, (b) impaired neuromuscular efficiency of the superficial prime movers, and (c) impaired recruitment of the deep cervical flexors that appears to be compensated for by increased superficial muscle activity (5, 61, 67-70, 123, 125, 126).

**Time-dependent methods.** There are several time-dependent methods that can be used to evaluate neck muscle endurance. These are dependent of the type of desired contraction; static, dynamic, or isokinetic. A static time-dependent method uses the
duration a participant is able to maintain a submaximal or maximal isometric contraction to assess the relative or absolute static endurance respectively. Dynamic endurance examines the ability of a participant to perform repeated maximal or submaximal contractions, usually through a full ROM at a specified cadence. The isokinetic mode of endurance assessment has several options, including: (a) 50% decrement test, (b) endurance by time test, (c) endurance by repetition test, and (d) 50 repetition decrement test. For a further description of these tests refer to Strimpakos (201). The static, and some dynamic, time-dependent assessment modes provide a gross estimation of cervical musculature endurance. The majority of these tests are relatively simple to conduct in a clinical or research setting and require little equipment. Isokinetic, and in some situations dynamic, time-dependent assessments require trained staff and specialized equipment (such as a Multi-Unit Cervical Resistance machine or an isokinetic dynamometer). One of the benefits of these modes of assessment is the elimination of a number of measurement errors in the protocol, as the researcher/clinician is able to control these objectively. For example, cadence is controlled electronically rather than by the tester. However, this comes at a cost both in terms of time and expenditure. For an illustration of the different methods of evaluating cervical muscular endurance see Figure 2.7.
2.12 Research Examining Neck Muscular Endurance

To objectively assess endurance performance of the cervical musculature, researchers have used tools such as Borg RPE scales (5, 68, 72, 208), TTF values defined as the length of time a contraction is maintained (6, 68, 72, 163, 179), area under the force curve (6), and neuromuscular evaluations using EMG (5, 65, 78, 172, 209). In some cases a combination of these methods is used. The following is a brief examination of some of the methods used to assess neck musculature endurance.

2.12.1 Tests examining the deep neck flexors

Research has highlighted the importance of the neck flexors in patients with chronic NP, whiplash and headaches; in particular the role the deep neck flexors play in differentiating between those with and without pain (61, 65, 70, 124, 179, 180, 182, 183, 210-214). Three tests have been utilized to examine the endurance capacity of these flexor muscles; (a) the C-CF test (performed in supine upper cervical, flexion is evaluated using an inflatable pressure biofeedback unit placed behind the neck) (69, 128, 183); (b) the cervical flexion test (performed in a supine position, participants are
asked to tuck their chins and raise their heads up off the bench and maintain this position until fatigue or a prescribed duration) (61); and (c) the weighted cervical flexion test (using a goniometer fixed just above the ear and a 0.5 kg weight placed on the forehead, participants are required to lift their head from the bench to 10° of cervical flexion and hold for 60 s) (215). The C-CF test is used to evaluate the deep cervical flexors while the cervical flexion test and the weighted cervical flexion test examine both the deep cervical flexors and the superficial flexors (SCM and AS) (59, 69, 128, 183, 215).

A number of studies have used surface and intramuscular EMG to evaluate muscle activation levels in the deep and superficial flexors (61, 69, 78, 124, 128, 183, 216). EMG has also been used to determine neuromuscular recruitment patterns of these muscles during the C-CF test and the cervical flexion test (61, 69, 124, 125, 183, 210, 211). The majority of research using the weighted cervical flexion test has solely examined TTF as opposed to EMG measures (215). Both the cervical flexion and weighted cervical flexion tests use low loads to examine the endurance capabilities of the neck flexors.

2.12.2 Absolute and relative load submaximal endurance tests

Fewer research studies have employed low load submaximal tests to evaluate the endurance capacity of the cervical extensors. For this type of test, participants lie prone on a bench with the head and neck unsupported. The head is placed in a neutral position with the chin retracted. Using a strap that surrounds the head, a weight (1.5 kg for females and 2 kg for males) is suspended from the head. The participant is asked to maintain this position for as long as possible, with a maximum timeframe of 180 s. The test is terminated if the neck position changes by more than 5° (163, 215). Other researchers have modified this extensor endurance test by removing the weights from the head and extending the 180 s maximum timeframe to 600 s (217). Edmondston et al. (163) compared the relative and absolute reliability of the cervical flexion test and the extensor endurance test. They reported a larger ICC$^{(3,1)}$ for the flexor test (0.93) than the extensor test (0.88), however, both tests had good to excellent relative reliability. The same trend was displayed for the standard error of measurement (SEM) and minimal detectable change (MDC) measures which were 6.4 s and 17.8 s respectively for the flexor test and 25.8 s and 71.3 s respectively for the extensor test.
These values indicate that the cervical flexion test was more reliable or alternatively, that the cervical flexors test more consistently than the extensors (163).

Another method of static time-dependent endurance assessment examines the maintenance of absolute or relative (% of MVC) loads for a set duration or until an individual fatigues (5, 71, 72, 202, 209). The majority of this research has been conducted with helicopter or fighter pilots in seated positions where the trunk and shoulders have been restrained (5, 6, 72, 172, 209). Two of these studies examined Flx and Ext endurance using a DBC 140 device (David Back Clinic International, Vantaa, Finland) and assessed fatigue using EMG recorded bilaterally over the splenius capitis muscle (172, 209), the erector spinae at C7 level, and SCM (209). Ang et al. (172) used an absolute resistance load of 16 Nm for Flx and 28 Nm for Ext. This study used normalized EMG slopes as an index of fatigue for helicopter and fighter pilots with and without NP. The authors reported that helicopter pilots with NP had lower EMG slopes than their pain-free counterparts. For the endurance parameters examined there was no difference between the fighter pilots with NP and those without (172). In comparison, Thuresson et al. (209) examined the intra-rater reliability of sustained isometric contractions using a resistance load of 75% of the respective participants’ MVC for Flx and Ext. Consistent with the previous study, fatigue was assessed using EMG median frequency. The authors reported the highest inter-day reliability for endurance trials that exceeded 45 s for all electrode placements (SCM, erector spinae at C7 level, splenius capitis). Harrison et al. (5) examined cervical muscle function in helicopter aircrew using an isometric endurance load of 70% of MVC in Flx, Ext, LtFlx and RtFlx. Normalized mean EMG frequencies were used to monitor muscle fatigue of the splenius capitis, SCM, and upper trapezius to determine which muscles fatigued and therefore limited force maintenance during each endurance trial. They found that the small muscles (splenius capitis and SCM) fatigued to a greater extent than the larger muscles (trapezius). This significant drop in the mean EMG frequency in the small muscles coincided with an inability of the participant to maintain the 70% force load. Neuromuscular fatigue was not observed in the trapezius for any direction during the endurance trials (5).

TTF for submaximal muscular endurance trials have been used as an index of muscle fatigue (5, 6, 71). A study focusing on a sample of helicopter and flight engineers (n=
40) examined the length of time individuals were able to sustain 70% force load in Flx, Ext, LtFlx and RtFlx. The results revealed that Flx TTF (40.6 ± 15.6 s) was significantly less than Ext (55.6 ± 34.5 s) with no difference between LtFlx (65.3 ± 33.5 s) and RtFlx (62.4 ± 31.2 s) (5). TTF values have also been used to evaluate the effects of two neck specific interventions in helicopter aircrew relative to a control group (6, 71). A protocol, similar to that used by Harrison et al. (5) of a 70% MVC resistance load was employed to examine changes in TTF for Ext, Flx, LtFlx and RtFlx following the implementation of a 12 week neck specific intervention programme. The combined TTF values for the intervention groups and controls prior to the intervention were marginally higher (Flx: 47.34 s, Ext: 69.02 s, LtFlx: 85.51 s and RtFlx: 80.44 s) (71) than values reported by Harrison et al. (5). Data analysis revealed that the prescription of a muscle coordination program targeted at the neck resulted in significant improvements in the TTF for Flx (26.34 s), LtFlx (23.54 s) and RtFlx (28.72 s), while the control groups’ TTF remained unchanged or decreased for LtFlx by 27.44 s (71). A study by Alricsson et al. (72) examined the impact of a neck strength and endurance intervention on TTF in the cervical extensors of fighter pilots. To evaluate the endurance capacity of the pilots’ cervical extensors, they were tested in a seated position wearing a flight helmet that was attached to a dynamometer anchored to the wall. The experimental protocol isometrically loaded the cervical extensors using a resistance load equivalent to 196 N until volitional fatigue. The authors noted that a supervised neck exercise intervention programme resulted in improvements of 53 s in the neck extensor performance in the experimental group, while the control group decreased by 33 s (72).

2.13 Selection of Methodological Approaches for the Neuromuscular Assessment of the Neck

Training to improve strength, fitness, and individual and team skill acquisition is an accepted practice in both professional and amateur sport (129). In this context, training programs targeting the lower or upper limbs have been shown to reduce the incidence of injuries to both the knees and shoulders (129). Until recently, the efficacy of a neck specific exercise intervention as a method for the prevention of neck injuries had not been explored. A very recent study by Naish et al. (73) conducted a two year retrospective analysis of the effectiveness of a 26 week isometric neck specific
intervention on reducing the number and severity of cervical spine injuries in a professional rugby squad (n= 27). The application of an isometric neck exercise intervention in a professional rugby team resulted in a significant decrease in the number of match neck injuries sustained over a season. Eleven were reported in the 2007-08 season prior to the intervention and two in the 2008-09 season after the intervention had been implemented (73).

As discussed, minor neck injuries occur at a high frequency during rugby match play (30, 36, 87), and when compared to the lumbar and thoracic regions, the cervical spine was the most frequently injured region (30). NP is one of the primary symptoms of minor neck injuries (64), and is particularly prevalent in amateur rugby players, particularly in the forward positions (44). Currently no case-control evaluations of the osteoligamentous or neuromuscular systems have been conducted that compare athletes with NP involved in collision sports, to pain-free controls. Studies involving other populations and using various tools to evaluate performance have demonstrated that individuals with NP have: (a) greater fatigability of the superficial prime movers, (b) impaired neuromuscular efficiency of the superficial prime movers, (c) impaired recruitment of the deep cervical flexors compensated for by increased superficial muscle activity, and (d) impaired peak force production in the cervical musculature (5, 61, 67-70, 123, 125, 126). MRI imaging has been used to examine the osteoligamentous system of rugby players and has revealed degenerative changes in the disc and cervical vertebrae when compared to controls (47, 83). Similar impairments have been reported for CJPS and cervical ROM (48, 51). As the majority of cervical stabilization is provided by the cervical musculature, factors that impair or compromise the functional capacity of these muscles could potentially result in injury or the occurrence of NP, particularly in rugby players (64, 115).

Neck strength and endurance have been highlighted as valuable tools for the clinical assessment of individuals with NP, and/or injury, and for the documentation of progress in response to the implementation of a neck specific intervention (58, 59). Due to the technological issues surrounding the anatomical and mechanical axis of rotation when evaluating the neck isokinetically, for the present research it was elected to design a device that assessed neck strength isometrically (59). Portability was an important factor as it was to be used in field-based settings; however, measurement validity and
reliability of the device were also essential considerations. Practical issues regarding participant stabilization during assessment led to the selection of a fixed frame dynamometry device (58, 59). Although handheld dynamometry is the most portable method of strength and endurance assessment for the neck, this method is vulnerable to examiner bias, which can affect the reliability and validity of the results. The ability to stabilize a participant in a field-based setting was another methodological concern with a handheld dynamometer. Based on previous evidence concerning degenerative changes in the cervical region of rugby players and the methodological considerations, all testing was conducted in a neutral neck posture using a fixed frame dynamometer (47, 83, 98).

Most neck strength research has been conducted in either a seated or supine position (6, 76, 88). In the seated position, isolation of the cervical musculatures has been achieved by securing the trunk with a four-point safety harness (6, 76) in combination with techniques which limit the force contribution from the legs (95, 163). While these apparatuses and protocols have provided valid and reliable measures of cervical strength, the approaches are of questionable relevance to collision sports such as rugby, where the majority of neck injuries occur during contact events while players are running or tackling in the horizontal plane. Thus one of the purposes of this thesis was to design a testing apparatus that assessed neck strength and endurance in a novel body position that simulated the posture adopted by players when going into contact.

### 2.14 Research Examining Neck Strength in Rugby

As previously highlighted, there are a number of potential mechanisms and factors that influence the occurrence of neck injuries during impact events. The potential role the cervical musculature may play in the mitigation or minimization of injury to this region of the spine has been discussed. If the cervical musculature does play a role in injury prevention it is essential to monitor these muscles and observe any changes in strength and endurance that occurs as a result of exposure to a season of rugby. Despite the frequency of minor neck injuries and the potential mitigating role the cervical musculature may play, a limited number of studies have quantified cervical strength in rugby players (74-76).
Isokinetic cervical strength testing in Flx, Ext, LtFlx and RtFlx was conducted over a single session in 189 South African males who played rugby at a provincial level. The large sample size in this study enabled the authors to group participants based on playing positions (front row, second row, back row, and backs). The second row players had the highest peak torque values for Flx and LtFlx, the front row for Ext, and the back row for RtFlx. When position specific data was compared for the forwards, the only significant difference was isolated for Ext, where the front row forwards tested stronger than the back row forwards (76). This is likely due to the large metabolic demands placed on the cervical extensors of the front row forwards during scrumming. When the forwards were grouped together, their peak torque values were significantly greater than the backs. When peak torque values were corrected for body weight (peak torque/body weight) the only significant differences that remained between the forwards and backs were for Ext and RtFlx (76). This study provides valuable insight into the strength profiles of the various positions, however, methodological issues associated with the biological and mechanical axis of rotation when evaluating peak torque in this region of the body raises questions regarding reliability (58, 59). Thus assessment of neck strength isometrically may provide a more reliable measure of strength.

In a methodological review of cervical strength, isometric assessment was endorsed as the most reliable evaluation tool, which presented the smallest level of injury risk for the participant (58, 59). A recent study examined the reliability of cervical strength assessment using a handheld dynamometer in 25 academy-level rugby players (16 forwards and 9 backs). The authors assessed strength on two separate occasions. During each testing session three MVCs were conducted for Flx, Ext, LtFlx and RtFlx. Although the forwards demonstrated a trend towards greater strength, the only significant difference was isolated for Ext (forwards 637.10 N and backs 537.87 N) (74). While the mode of assessment used in this study is simple and widely available, the examiner must provide the resistive force during the testing and the participant must be stabilized in order to perform an isometric contraction (58). Although, the relative (ICC: 0.80-0.85) and absolute reliability (SEM: 18.49-40.57 N) values reported for the four tested directions ranked from good to excellent (74). Two reviews examining cervical strength measurements have stated that reliability and validity when using a handheld dynamometry are vulnerable to examiner bias (58, 59). Additionally, based
on the method of force application required and the prevalence of degenerative changes in the cervical spines of rugby players (47), the potential for injury during cervical strength assessment using a handheld dynamometer may be higher. Therefore this method was considered unsuitable for the study described in the present research.

The most common method of isometric cervical strength assessment in the literature is the use of a fixed-frame dynamometer (58, 59). This mode of assessment has been used to examine both professional (73, 88) and youth rugby players (75). At the professional level, studies have examined the effectiveness of a neck strengthening intervention in a team environment (73) and in a case study following a neck injury to loose-head prop (88). While these studies evaluate the effectiveness of their respective neck exercise programs, there is currently no research to indicate what normally happens to neck strength or endurance over a season of rugby with no intervention in place.

### 2.15 Neck Specific Exercise Intervention for Rugby Players

Phase 3 in the ‘Sequence of Prevention’ framework examines the introduction or implementation of rule changes, equipment or the implementation of injury prevention programs based on evidence from Phase 1 and 2. As indicated previously, the injury prevention literature highlights minor neck injury as the most prevalent injury to the cervical spine. Examination of the phase or play and factors of mechanism that may prevent or mitigate the occurrence of these minor neck injuries has illustrated that the neck musculature may provide a possible means to achieve these outcomes.

The use of exercise interventions to improve muscular strength, endurance, fitness, individual and team skill performance is an accepted practice in the area of sport and recreation (129). In addition, a commonly conducted practice in the area of rehabilitation, strength and conditioning is the use of exercise interventions for the prevention or minimization of injury in sports (91). In many cases there is little scientific evidence to support this practice. A notable exception is for lower limb injuries, specifically prevention strategies aimed to reduce the frequency of anterior cruciate ligament injuries (218-220). Where neck injury prevention is concerned, a number of position papers have recommended inclusion of neck specific exercises to prevent or minimize the severity of neck injuries in rugby or other collision sports (27, 54, 56, 57, 129, 221), despite a relative lack of scientific evidence to support these
claims (221). There is however a growing body of evidence to support this position in the general population (55). In a systematic review examining the conservative management of mechanical NP, the authors presented moderate evidence for long-term improvement in function following the application of neck strengthening and stretching exercises (222). An earlier review on the effectiveness of neck exercise alone concluded that there was strong evidence to support the efficacy of dynamic resisted strengthening and proprioceptive neck specific exercises (223).

Despite a lack of empirical evidence, it has been proposed that hypertrophy of the cervical musculature may translate to enhanced energy absorption capabilities, resulting in improved ability to maintain a neutral cervical spine during loading events (56, 174, 221, 224). Mansell et al. (91) suggested that the head-neck segment dynamic stabilization system could theoretically provide protective properties similar to those documented in the knee and shoulder (225-227). Dynamic stabilization is dependent upon both feed-forward and feedback mechanisms to coordinate movement patterns in anticipation of and in reaction to movements, or the application of a load (91). As discussed earlier (Chapter 2: 2.7.2 Phase 2), co-contraction of the SCM and the trapezius muscle prior to the application of an impulse load has been shown to reduce head displacement and acceleration through feed-forward mechanisms of motor coordination (130, 153, 157, 158). The feedback mechanism of control relies on reactive muscle activation and uses neural reflex pathways to regulate movements (91). These reflex responses in the cervical muscles are regulated by sensory input received by the vestibular, visual and mechanoreceptors in the head and neck (158, 228). Resistance training of this musculature may provide a functional stimulus to improve neuromuscular recruitment patterns and control (51), thereby increasing the rate and amount of muscle force development (91, 225). It is this improvement in the rate and amount of force development that may enhance dynamic stabilization of the neck to protect or minimize the severity or frequency of minor neck injuries.

This concept has been examined in two intervention studies focusing on the effects of cervical strength on head kinematics in a dynamic stabilization task undertaken by football players (91) and during a tackle in American gridiron players (90). In the dynamic stabilization task, football players were divided into a resistance training group and a control group that were assessed pre- and post-intervention. The dynamic
stabilization task required participants to sit inside a device wearing a head harness that was attached to a pulley system with a 50 N load on the opposite end. Their head and neck segments were impulsive loaded over a series of trials where knowledge of the impulse-loading event was manipulated. The outcome variables of interest were the head-neck segment kinematics and stiffness, EMG activity of the upper trapezius and SCM muscles, and isometric peak force in Ext and Flx. The resistance-training group incorporated neck specific exercises twice weekly for eight weeks into their regular gym training routines. The neck exercises consisted of isotonic cervical Flx and Ext using a neck resistance-training machine. The load was set at 55% of their respective 10 repetition maximum (RM) for 3 sets of 10 reps and the resistance load was progressed by 5% every two weeks. After completion of the post-intervention assessment no reductions in head-neck segment acceleration in the resistance-training group were reported, despite significant improvement in Ext and Flx peak force for the females and in Flx for the males. For the male participants no changes in muscle onset times for the SCM or the upper trapezius were observed. The authors concluded that these findings indicate the need for “neck muscle training tasks that elicit feed-forward and feedback motor control mechanisms to better use the dynamic stabilizers for both protection and performance enhancement” (91). To support this conclusion research focusing on other regions of the body has reported that ballistic activities (plyometrics) resulted in enhanced neuromuscular control and dynamic stabilization (225-227).

A similar study investigated the effects of an eight week isoinertial cervical resistance training program on both head and neck kinematics and neuromuscular activity of the SCM and upper trapezius during an American gridiron tackle. This study used EMG and ViconNexus® 3D motion capture system to measure these parameters. The intervention consisted of isoinertial Ext, Flx, RtFlx, and LtFlx exercises at a resistance load of 60-80% of the 10 RM for 3 sets of 10 reps 2-3 times per week. Significant improvements were observed post intervention for Ext (7%) and LtFlx (10%); however, these changes failed to augment the neuromuscular response of the SCM or upper trapezius, peak linear or angular head acceleration during the tackling task (90). As per the Mansell study, the authors noted that the exercises in the intervention failed to emphasize hypertrophy, muscle contraction velocity, and muscle co-contraction of the SCM and upper trapezius. This potentially explains the lack of significant findings. Another limitation that may explain the lack of statistical significance was the linear
acceleration values recorded during the tackling tasks. These ranged from 7.23-7.59 Gz (90) which are significantly lower than the average values recorded in tackling events for high school (23-25 Gz) (229) and collegiate (21-32 Gz) American gridiron players during games and training (144-147). As the linear acceleration values of the head obtained during this study did not exceed 8 Gz, the level of dynamic stabilization provided by the cervical musculature may have been sufficient to withstand the impulsive load imposed by the tackling task (90). To further examine the effect of a neck intervention program it may be necessary to expose individuals to larger impact forces that replicate those experienced in a game. However, there may be safety concerns with regards to exposing individuals to impact forces of these magnitudes.

The majority of cervical injuries sustained in rugby are classified as minor in severity (30) encompassing nerve root injuries, ligament sprains, muscle strains, and soft tissue contusions to spinal nerve pathologies (i.e. stingers, disc protrusions, joint pathologies) (54, 55, 230). Data on the prevalence of NP (the primary symptom of minor neck injuries) in these athletes is lacking (64), presumably due to the fact that surveillance efforts have primarily focused on catastrophic neck injuries (18, 24, 26, 27, 97, 132, 231). For tensile injuries (stingers) to the cervical regions, a rehabilitation strategy focused on cervicothoracic stabilization has been highlighted as a key in exercise program design (232, 233). Long-term hypermobility injuries to the cervical spine can lead to degeneration of the discs and the cervical vertebrae, which can progress to the development of arthritis in this region. In addition to these arthritic symptoms, research examining the long-term impacts of this degeneration has observed neuroforaminal narrowing and predisposition to nerve root or spinal nerve pathologies in the affected individuals (233). To manage the existence of these pathologies a number of authors have recommended the inclusion of general cervical muscle strengthening exercises in the normal training routine for athletes participating in collision sports (53, 54, 233). Specifically, Cross and Serenelli (54) state that “the incorporation of such exercises may be of great benefit as preventative measures against hypermobility of spinal segments and violent excursions of the cervical spine, which may lead to a non-catastrophic injury to the cervical spine.”

In rugby the majority of evidence surrounding the use of neck specific interventions is limited to position papers (56, 57, 234), or a single case study (88). Subsequent to the
design of this thesis the results of a recent two year retrospective analysis conducted by Naish et al. (73) examined the effectiveness of a 26-week isometric neck specific intervention on reducing the number and severity of cervical spine injuries in a professional rugby squad (n= 27). In the first year, the 2007-08 season functioned as the control and the intervention was implemented over the 2008-09 season. The intervention consisted of two 13-week mesocycles. The first mesocycle focused on strengthening, while the second mesocycle progressed participants into a maintenance phase. The selection of neck specific isometric exercises ranged from non-specific to position specific exercises, which incorporated different body and upper limb positions. The results from the 2007-08 season showed 12 neck injuries were sustained and this number deceased to six in the 2008-09 season; however, this decrease was not statistically significant. A similar result was produced for time lost due to injury, measured as the number of trainings and games missed due to neck injury. During the 2007-08, a total of 100 days were missed and in the 2008-09 season a total of only 40 days were missed. Further analysis regarding the occurrence of these injuries revealed a significant decrease in the number of match injuries sustained with 11 reported in 2007-08 and two in 2008-09. In addition to the injury surveillance data, a pre-season and week five assessment of isometric neck strength of the programme was conducted. The authors reported a non-significant increase in neck strength for all four examined directions (Ext, Flx, LtFlx and RtFlx) (73). However, the small sample size and the lack of a post-season assessment make it difficult to attribute the decrease in injuries to improvements in cervical strength. The gaps in the literature confirms the need for research to examine the efficacy of a neck specific exercise intervention in a professional rugby team using a pre- and post-season season assessment of neck strength and endurance.

2.16 Conclusion

Participation in collision based sports such as rugby exposes athletes to an increased risk of neck injury (55). The majority of these injuries are classified as minor in severity and do not result in prolonged absence from training or match play (30, 36). However, given the frequency of these events (30, 36) and the identified degenerative changes seen in this region of the spine (47, 83), the potential for long-term health impacts are a major concern for current and retired players. Research has been
conducted to examine neck strength in rugby players using single observational studies (74-76), however these studies fail to explain how cervical strength may change over the season. Injury surveillance suggests that neck injury frequency at the professional level increases as the season and the game progress (20, 30). Therefore, given the currently accepted notion that neck strength may have a protective effect on the frequency of neck injuries, it is likely that neck strength decreases over the season.
Chapter 3

The Long-term Consequences of Neck Injury in Rugby
Chapter 3 – Impact of Rugby Participation

Chapter 3: The Long-term Consequences of Neck Injury in Rugby

Chapter 4: Experimental Protocol and Design of the Fixed Frame Dynamometer to Assess Neck Strength and Endurance in a Simulated Contact Posture

Part I: The Reliability of Repeat Isometric Neck Strength Testing in a Simulated Contact Posture

Part II: Reliability of Repeated Trial Isometric Neck Strength and Endurance Testing in a Simulated Contact Posture

Chapter 5: Monitoring of: Neck Strength, Endurance, Neck Pain and Stiffness over a Season in a Cohort of Amateur Rugby Players and Controls

Chapter 6: Design of a Neck Specific Exercise Intervention for Rugby

Chapter 7: An Examination of a Neck Specific Intervention in a Professional Rugby Team Relative to a Control

Chapter 8: Summary, Strengths and Limitations, Future Research Directions and Conclusions
3.1 Introduction

Despite the high level of participation and historical psychological/social value placed on sport there is an inherent risk involved with sport engagement, and increased participation elevates this injury risk (54, 55). With the advent of professionalization in rugby union the risk of injury has been amplified (110, 111, 113) The study of retired professional athletes offers a unique opportunity to evaluate the long-term impact of sport participation. To date the research in this area has primarily been conducted with American gridiron, football and boxing with the major foci on musculoskeletal and concussive brain injuries and the effects these injuries had on the subsequent development of osteoarthritis, cognitive and behavioural sequelae respectively (101-109).

Currently there is little research examining the long-term health impact of participation in rugby. One of the landmark studies in rugby has examined the global concept of injury and the subsequent health impact this had in players four years post injury (113). A total of 911 participants responded to this retrospective survey and of these 35% ($n=91$) reported that the injury had a “temporary or significant effect on [their] education, employment, family life, or health and general fitness” (113). Of the 390 individuals retired from the sport during the examined timeframe the most common reason attributed to retirement was injuries sustained while playing rugby (113). Collectively, these findings begin to highlight the effects injuries have on participants’ quality of life, their family environment, and their decision to retire from rugby.

As professional rugby players more frequently sustain neck injuries when compared to amateurs (26, 27, 46, 110, 111), it is feasible to predict that the long-term impact of these injuries is likely to be greater for retired professional players. Currently there has been no examination of the long-term impact neck injuries sustained during collision sports have on players once they retire. Research in this area is limited to injury surveillance studies conducted with current players (20, 24, 26, 30, 36, 52, 87, 100, 140). An investigation into non-catastrophic injuries of the three regions of the spine found that professional rugby players were significantly more likely to sustain an injury to the cervical spine than the thoracic or lumbar region (30). This highlights the vulnerability of this region of the spine, which functions as a mobile column located between the bulk of the torso and the head.
Forces and constraints imposed on cervical motion during contact events (tackling and scrummaging) during rugby have been linked with early degenerative and onset of cervical lesions (31, 47, 83, 98, 235). To explore the potential mechanisms for these pathological changes compression forces during simulated scrummaging have been examined, where forces up to two thirds of a tonne in the necks of the front row players have been recorded (151). These compression forces during the scrum have been correlated to the high incidence of cervical facet joint injuries in front row players (30). Biomechanical evaluations of cervical spine injuries have established a relationship between the occurrence of facet joint injuries and the presence of osteoarthritis in the cervical spine (130). The degenerative changes observed in veteran and retired professional front row players supports this hypothesis (83). Thus, the forces experienced by front row players during a scrum contribute to the occurrence of facet joint injuries in the cervical spine and these potentially lead to the development of degenerative changes documented in the cervical spine of these players later in life (30, 83).

Current research indicates that pathological changes to the osteoligamentous system of the cervical spine are no longer isolated to front row forwards (47). A study examining 127 professional players encompassing all positions using static MRI reported that over half the population presented with cervical abnormalities (47). A potential explanation for these observed changes is the evolution of the professional game to involve more collisions (tackles, rucks, mauls) (27, 47). The forces experienced at the neck during these collisions are unknown; although, work with American gridiron has documented head acceleration values in the range of 56-169 Gz (90, 144-147). In summary, pathological changes to the osteoligamentous system of the cervical region have been observed to increase with the length of a career and were absent in age matched controls.

Pathological changes to the cervical spine are not limited to the osteoligamentous system, but also extend to include cervical range of motion (ROM) and cervical joint position sense (CJPS). Research examining ROM in rugby players relative to controls has reported that forwards have significantly less cervical ROM than backs or controls. For the rugby players the deficit in ROM was positively correlated to the number of years played (48). In addition to documented changes in cervical ROM, impairments in
CJPS have also been shown in rugby players (44, 48, 51). A recent study examined CJPS in forwards ($n=10$), backs ($n=10$), and non-rugby playing elite athlete controls ($n=10$) and found similar repositioning errors in the forwards and backs. The authors reported that repositioning errors obtained by the rugby players were consistent with previous work conducted using the experimental protocol with older adults (age $>$ 65 yrs) and neck pain (NP) patients (51). These findings highlight the impact rugby participation has on the osteoligamentous and neuromuscular systems of current players. Currently no research has examined the long-term impact degenerative cervical spine changes have on the health of retired players. Do these observed changes to the cervical spine affect long-term health status or ability of these retired players to perform activities of daily living? Data relating to the prevalence of NP in rugby is limited, to a single observational study of amateur rugby players that reported NP affect 83% of forwards and 41% of backs (44). These findings were substantially higher than the prevalence reported for an adult population (15-74 yrs of age) that ranges from 5.9-22.2%, with a mean prevalence of 7.6% (45). Although, these statistics provide information regarding the prevalence of NP, there is no indication of the impact this NP is having on the health status of the individual.

Clinicians and researchers have employed disability scales to explore the impact NP has on an individual’s quality of life and ability to complete everyday tasks. One example of these is the Neck Disability Index (NDI), a 10-item self-reported psychometric instrument used to assess disability in patients with NP (236). It was originally developed as a modified version of the Oswestry Disability Index to assess NP in 1991 by Vernon et al. (236). Typically this instrument is used to assess disability in patients with chronic mechanical NP or individuals who have sustained a whiplash injury during a motor vehicle accident (237, 238). While these studies provide insight into the level of disability in these patients, without normative data it is difficult know what level of disability the general population would report. Only a few studies have examined the use of this tool in healthy populations (239, 240), making comparisons difficult. However, the use of this tool may provide some insight into the level of disability in retired professional athletes and will permit comparisons of their level of self-reported disability related to NP to other populations.
The physical nature of rugby implies that injuries are an inherent aspect of the game. The findings of a two year study of an elite Welsh rugby club support this conclusion, where over the season it was reported that no player was pain or injury free (99). Based on the frequency of pain episodes during the career of a player it is feasible to expect that in order to continue playing some players have built up or increased their level of pain tolerance. In an attempt to capture and explore potential impairments that do not relate to the experience of pain, the concept of stiffness was introduced. For the purposes of this study the definition of stiffness as originally developed by Davis and DeLuca was adopted (3). They defined stiffness as the resistance that a joint offers during movements or when starting a movement and/or feelings of tightness and resistance to stretch in the muscle in the absence of pain (3). Use of this construct may permit the identification of individuals who may have adapted to the constant level of pain in the affected joint and/or muscle and may not report the pain but are still experiencing some level of impairment in the affected region.

The purpose of this study was to examine the long-term effects that rugby participation has on the cervical spine and subsequent health impacts. Examination of this issue is essential not only for retired and current athletes, but also for medical personnel, administrators and rehabilitation specialists involved in the sport. The information from this survey can facilitate examination of rules and regulations of the game by governing bodies to allow the implementation of changes to prioritise players’ current and indirectly improve long-term health outcomes for their players. In addition, the results can also be used to help guide rehabilitation protocols and programs, for future and currently retired athletes, to reduce the impact of identified health concerns. Results from this study will also provide currently injured players in the process of making decisions regarding treatment options and/or the possibility of return to play or retirement, with information about the potential impact their decision may have on their long-term health.

3.2 Research Questions

To establish whether NP and NS was a health concern for players once they retired, the health status of retired professional rugby players was examined. The primary purposes of this chapter were the following:
1. To retrospectively document the number of cervical injuries sustained during playing careers,
2. To retrospectively document the number of cervical injuries sustained during playing careers that required surgical interventions,
3. To explore the use of specific neck exercises in the treatment of neck injuries,
4. To investigate current NP and NS in retired professional rugby players,
5. To examine retired professional rugby players’ levels of chronic NP and disability using the NDI.

The injury surveillance literature has indicated that forwards sustain proportionally a higher number of neck injuries when compared to backs (20, 27, 30, 52). Despite this discrepancy with regards to injury frequency, players in both positions present with documented changes in the cervical osteoligamentous and neuromuscular systems (47, 48, 51). Thus, the secondary purpose of this study was to compare the level of current NP, current NS and NDI scores in forwards and backs.

### 3.3 Methods

#### 3.3.1 Research design

This study used an online survey methodology to document neck injuries and the continuing impact these injuries may have on the lives of retired rugby players. The design of this study incorporated key principles of survey methodology such as: (a) use of multiple contacts, (b) personalization of introduction e-mail to the extent possible, (c) implementation strategy, (d) question format and content, (e) design of respondent friendly survey as outlined by Dillman et al. (241). In addition the checklist for reporting results of internet E-surveys (CHERRIES) was utilized where appropriate (242). The retrospective anonymous survey included questions on: personal descriptors, playing history, all injuries sustained during their careers, current levels of all pain and stiffness, current physical activity levels and current NP and NS.

#### 3.3.2 Ethics

Institutional ethical approval was obtained from the University of Otago Human Ethics Committee (Appendix A).
3.3.3 Research collaborators

As the survey was developed in English only the Players’ Associations and Rugby Unions where English was the first language were considered for participation. The Players’ Associations were approached through the contact listings on their respective websites or from referral through a representative from the International Rugby Board (IRB) Players’ Association. A working relationship was established with the IRB Players’ Association and Players’ Associations from the following countries: Australia, England, Ireland, and New Zealand and the Canadian Rugby Union. As a number of Rugby Unions (South Africa, USA, and Fiji) did not have the infrastructure in place to communicate with their retired players, it was therefore not possible to include them in the survey. Following completion of the survey the respective unions were provided with a summary of the survey results.

3.3.4 Participants

Participants were male professional rugby players who retired from professional rugby between the years of 1995-2012. Respondents were volunteers recruited through the participating Players’ Associations and Rugby Unions. Prior to data collection, each participant was fully briefed via e-mail about the goals of the project (Appendix B). The voluntary nature of the project and the confidentiality of outcomes and medical information were emphasized to all participants.

As there is no international directory of retired players and membership to the respective Players’ Associations is voluntary, there is no sound estimate of the potential size of the available sampling frame, thus it was not possible to formally establish the sample size. Thus a pragmatic approach was used to gather as many participants as possible via the collaborating Players’ Associations and Rugby Unions.

3.3.5 Development of survey content

In order to meet the study objectives a comprehensive review of previous literature exploring the impact injury history has on the current health status of retired professional athletes was conducted. In addition input was sought from an international expert (Prof. Stephen Marshall, University of North Carolina, USA) who had examined the long-term health status of retired NFL players (105, 106, 243) and contributed to
the landmark Rugby Injury Performance Project Pre-Season Questionnaire study (244). Access to these surveys was provided and their content examined for relevance to the current study. As there is limited research available that has examined the long-term health of retired rugby players, findings from injury surveillance studies on current players were examined to ensure appropriate content for questions relating to injuries sustained during their career (20, 30, 52, 245).

3.3.6 Development and design of the survey

A reference group consisting of group of local sport science and medicine researchers (Dr. Phil Handcock, Prof. John Sullivan and Ass Prof. Nancy Rehrer) was established to analyse and discuss potential areas of interest. Following a comprehensive search of the sports medicine literature surrounding retired professional athletes and the assessment of NP, and international consultation (Prof. Stephen Marshall, University of North Carolina, USA) a draft bank (Version 1) of questions was established. These questions were then discussed with the reference group as to their relevance to the goals of the study and metrics. This lead to a revision of the questions and their formats (Version 2). This version was sent to an international expert (Prof. Stephen Marshall, University of North Carolina, USA) in sport medicine methodology and surveys addressing the health of the retired athlete. His feedback was discussed with the same reference group who incorporated the suggestions and comments into the development of the questionnaire (Version 3). Version 3 was then circulated to the representatives from the participating Players’ Associations and Rugby Unions for comments and critical feedback. In particular feedback was sought on the relevance of the questions to their respective members and on the suitability of the wording for their cultural context. This feedback was examined by the reference group and a revised draft of the questionnaire was created (Version 4). An outline of this process is presented in Figure 3.1.
Figure 3.1: Summary outlining the key steps in the design of the survey

1. Comprehensive review of literature relating to: (1) health status of retired professionals (2) neck injuries and their assessment
2. Examination of the content of relevant surveys
3. Examination of the preliminary draft of the survey by the reference group
4. Examination of the survey by international expert
5. Examination by IRB Players' Association and participating Players' Associations and Rugby Unions
6. Format of questions and questionnaire
7. Design of a hard copy version
At this point the format (categorical and open ended questions) was discussed and confirmed. The format of questions in the survey included: categorical (Yes/No), ranking, multiple response style questions, open ended free text questions, pain body diagrams and visual analogue scales (VAS) (246). This provided the basis for the development of an online version of the survey instrument. This was completed in collaboration with an information technology specialist experienced in the design of online surveys from the University of Otago, NZ. The survey was designed to be completed in approximately 15 min and allowed the respondent to navigate both forwards and backwards within the survey, and to save and return at a later time (241, 247). The survey was designed so that only one question appeared per page for ease of navigating (241, 242). In addition the survey employed the use of adaptive questions (certain items were only displayed based on the responses to previous questions) to reduce the number and complexity of the survey questions (242). These features were included to facilitate maximum participant response (241, 242).

In order to facilitate response by an international audience, participants had the opportunity to respond to questions in different units of measurement (i.e., pounds, kilograms) based on which Players’ Association or Rugby Union they belonged to. In addition, the selected software framework for the survey permitted the use of body diagrams with hot spots that allowed the participant to click on specific areas (see Figure 3.2). These body diagrams were used to identify areas of injury, locations of surgeries, current areas of pain, current areas of stiffness and joints that were currently arthritic. The software also permitted the use of continuous sliding VAS (0 - 100 mm) for pain, stiffness and general health questionnaires as a way to producing a continuous numerical response to these questions.
3.3.7 Piloting of the survey

Piloting of the survey consisted of two distinct but related steps each with its own specific objective. For the current study the survey was initially piloted using the following methods: (a) a hard copy of the survey in face to face interviews and (b) an online version of the survey (Figure 3.3).

**Hard copy piloting process.** Piloting of a hard copy of the survey (Version 4) with a group of retired professional rugby players (n = 20) living in New Zealand was conducted to ensure content, clarity and the use of appropriate language for the questions.

**Online piloting process.** The online version of the survey was also piloted using a sample of 45 current and retired amateur rugby players from New Zealand, Canada and England, who were subsequently not included in the final survey. These pilot participants were selected to provide a comprehensive review of the survey content, focusing on the wording and terminology to ensure that the survey was suitable for an
international audience. The participants were instructed to provide feedback regarding the aforementioned variables to the candidate.

A final draft of the revised online survey was distributed to the participating Players’ Associations and IRB Players’ Association representative to ensure the language and content of the questions were clear and to determine whether there was any concerns raised with any of the questions. Collectively, this provided a strong element of content validity for the information included in the questionnaire and also provided an opportunity to screen for any questions of a personal nature which may discourage participation.

3.3.8 Survey content

The survey consisted of 11 sections designed to accrue information regarding the participants’ personal details, rugby career, history of injuries sustained throughout their rugby career, current levels of pain and stiffness, current fitness activities, and current health status. A complete version of the survey is provided in the appended CD at the back of the thesis. Each section examined in the current study is outlined in the Table 3.1 below.
Table 3.1: The sections of the survey

<table>
<thead>
<tr>
<th>Survey sections</th>
<th>Examined in current study</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Your personal information</td>
<td>Yes</td>
</tr>
<tr>
<td>2. Your rugby career</td>
<td>Yes</td>
</tr>
<tr>
<td>3. Physical injuries you sustained during your rugby career</td>
<td>Yes</td>
</tr>
<tr>
<td>4. Concussions(s) sustained during your rugby career</td>
<td>No</td>
</tr>
<tr>
<td>5. Questions relating to your rugby career</td>
<td>Yes</td>
</tr>
<tr>
<td>6. Pain and stiffness from rugby related injuries that you are feeling now</td>
<td>Yes</td>
</tr>
<tr>
<td>7. Your typical level of neck pain and neck stiffness</td>
<td>Yes</td>
</tr>
<tr>
<td>8. Neck disability index</td>
<td>Yes</td>
</tr>
<tr>
<td>9. Your current fitness activities</td>
<td>No</td>
</tr>
<tr>
<td>10. Questions relating to your present health status</td>
<td>No</td>
</tr>
<tr>
<td>11. A general health questionnaire</td>
<td>No</td>
</tr>
</tbody>
</table>

The present study focused solely on the sections that related to neck injuries or NP/NS and are described below. The sections were as follows:

**Personal information.** Participants were asked to provide basic personal descriptive information specifically age, weight (kg or lbs), height (cm or feet and inches), whether they were a smoker, their employment status and level of physical activity involved in their job. Information was also collected regarding the country where the majority of their professional career was spent and their Players’ Association/Union affiliation.

**Rugby career.** Respondents were asked to indicate their most common playing position, the highest level of rugby played (International, Super Rugby/Heineken Cup, National team), year they retired from professional rugby, and their age at retirement. A 100 mm VAS was used to indicate their level of satisfaction with their career anchored with the cues at 0 mm ‘very unsatisfactory’ and 100 mm ‘very satisfying’.

**Physical injuries sustained during their rugby careers.** This section included questions relating to injuries sustained during their professional rugby career. Respondents were instructed that a physical injury was defined as damage to their body resulting from movement or from contact with another player and/or the ground. Further to this they were informed that the injuries could have been sustained during game play and/or during training (248). For an event to result in injury the respondent was instructed that it was not necessary that medical attention was sought and/or that they were unable to play or train for rugby. Other questions related to surgeries
attributable to a rugby injury that were required during or after their career. Respondents were asked to indicate the five most frequently injured body sites, when most injuries occurred, what influenced their decisions regarding return to play from injury, and/or to retire. Participants also had the opportunity to respond to an open ended question “is there one injury that stands out in your career that you would like to tell us about.”

Questions relating to their rugby career. The focus of this section was whether or not a neck injury (disc injury, fracture, stinger, nerve injury) had been sustained or if they suffered from NP during their careers. Also examined in this section was information relating to the treatment of this injury, whether they were provided with neck specific exercises to rehabilitate their injury and the success of the treatment/exercises were explored.

Information relating to current pain and stiffness from rugby related injuries. Participants were asked to describe their current level of pain and stiffness from past injuries or areas of overuse. Pain was defined as: an unpleasant sensory and emotional experience associated with actual or potential tissue damage (1). Stiffness was explained as the resistance that a joint offers during movements or when starting a movement, such as walking or turning the head for example (3). Also included in this definition of stiffness was the concept of muscle stiffness which was defined as a feeling of tightness or resistance to stretch in the muscle in the absence of pain. It was explained that stiffness could change throughout the day, for example it may be worse in the morning or may improve or worsen during exercise (3). Using a sliding 100 mm VAS participants were asked to rate their level of both current pain and stiffness, average level over the past month and worst level over the past month. Scales were anchored at 0 mm with ‘no pain/stiffness’ and 100 mm with ‘worst pain/stiffness imaginable’. Participants were asked what activities they attributed this pain and stiffness to and then to rank up to five areas on the interactive body diagrams where they were currently experiencing pain or stiffness. The option was then provided to respond in an open ended format to the following question: “If you wish to provide further information regarding your areas of typical pain, please do so in the space provided.”
Current level of neck pain and/or stiffness related to rugby participation. Respondents were asked if they were currently experiencing NP. If the response was affirmative, participants were then asked if they could relate their current NP and/or NS to their past experience of playing or training for rugby. The remaining questions explored the intensity of their NP and/or NS, activities that aggravated symptoms of NP and/or NS, and whether the participant was seeking or had sought treatment for their NP and/or NS.

**Neck Disability Index.** Is the most widely used self-reported psychometric instrument for evaluating the status of NP and disability in clinical research (236-238, 249). The NDI is a standardized questionnaire consisting of 10 items addressing the effect a respondent’s NP has on the following functional activities: personal care, lifting, reading, working, driving, sleeping, and recreational activities. Also included in this questionnaire are items addressing NP intensity, headaches, and concentration. Each item is scored on a 6 point scale (0: no disability, 5: total disability) for a maximum total score of 50 (236, 238). The higher the reported score the greater the level of NP and disability. The score interpretation for the NDI has been reported as 0-4 none, 5-15 mild, 15-24 moderate, 25-34 severe, and scores > 34 completely disabled (238, 250).

3.3.9 Survey procedure

This study asked participants to recall injuries sustained as a result of their rugby participation and explored the relationship between injury location, severity and frequency and their current health status. To maintain participant anonymity respondents were contacted through their respective Players’ Associations or Rugby Unions, this contact was limited to those that had provided current e-mail information to their respective Players’ Associations/Unions. An initial introductory e-mail inviting participation was sent by the respective Players’ Associations/Rugby Unions on behalf of the candidate (251). The e-mail indicated that the respective Players’ Association and/or Rugby Union supported the research, outlined the purpose and goals of the study, assured respondents of the confidentiality of information and provided a link to the online survey (Appendix B).

The survey was launched by clicking on the link provided and entering the user code for security purposes. On the survey homepage respondents were instructed that they
were providing informed consent to participate in the study by entering the user code. Participants were able to log out of the survey and return at a later time to complete the remaining sections. As respondents and non-respondents could not be identified, all potential participants were sent two follow-up emails approximately two weeks apart through their Players’ Association (251), as the use of multiple contacts has been found to increase the average response rate (252). These follow-up e-mails thanked those who had participated and encouraged non-respondents to consider completing the survey (Appendix C). The survey was conducted at different points in time by the respective Players’ Associations and Rugby Unions over a period extending from April 23 to December 31st 2012. The responses were anonymously coded and the research candidate was blinded to the identity of the participants and the data could only be accessed by the candidate and the IT specialist associated with the project (242).

3.3.10 Statistical analysis

All data were downloaded from the survey server into an Excel spread sheet. The data were examined and any participant with a complete set of missing data was removed (242). SPSS 19.0 (IBM SPSS Statistics, Somers, N.Y.) was used for all statistical analyses, and the criteria for statistical significance was set at $\alpha= 0.05$.

3.3.10.1 Quantitative data

Simple frequencies and summary statistics were calculated for all examined variables. Where appropriate for the continuous variables, values are reported as a mean (SD). Histograms were checked for normality of distributions. All imperial anthropometric data (weight in lbs and height in feet and inches) were converted into metric values. A One-way ANOVA was conducted for the continuous anthropometric variables and rugby career related data to compare the forwards and backs. For the top five most frequently injured body areas during their career and the top five areas of current pain and stiffness questions weighted ranking scores were calculated. These scores were calculated by assigning a value of 5 to the 1st ranked area of pain or injury and a value of 1 to the 5th ranked. Thus when combined created a weighted ranking score. For the injury and surgery ranking questions, the categorical values for primary mechanism of injury was assessed using a cross tabulation. As previous research has documented higher levels of NP in forwards when compared to backs the total scores for the NDI
were blocked into forwards and backs and compared using one-way ANOVA. A non-parametric Mann-Whitney U test was used to examine each of the individual items of the NDI, since the data for these variables was usually skewed (253, 254). Post-hoc examination of this data was conducted using a Monte Carlo significance test (253).

### 3.3.10.2 Qualitative data

For those participants that responded to the open ended question “is there one injury that stands out in your career that you would like to tell us about?” responses were collected verbatim and grouped based on body areas indicated in the response. For those responses that highlighted the neck as an area of frequent injury the quotes were examined to identify common themes and were presented in tabular form. The classification of the quotes was conducted by the candidate and verified by a member of the supervisory team. Individual verbatim quotes are presented by participant number.

### 3.4 Results

The survey was completed by 255 retired rugby players from four Players’ Associations and one Rugby Union. Of those who responded 213 indicated that they had participated at a professional level. As rugby union only became a professional sport in 1995, only those who indicated retirement in 1995 or later were included for analysis, leaving a sample size of 195 participants. The response rate from each Rugby Union or Players’ Association that participated in the survey (Table 3.2) ranged from 10.78 – 43.00%. The overall response rate for the survey was 26.53%.
### Table 3.2: Response rates from the participating organizations

<table>
<thead>
<tr>
<th>Players’ Association/ Union Membership</th>
<th>Survey sent to</th>
<th>Number of respondents</th>
<th>% of individuals that completed the survey</th>
<th>% of total sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia’s Rugby Union Players’ Association (RUPA)</td>
<td>214</td>
<td>34</td>
<td>10.78</td>
<td>13.3</td>
</tr>
<tr>
<td>Canadian Rugby Union</td>
<td>200</td>
<td>87</td>
<td>43</td>
<td>34.1</td>
</tr>
<tr>
<td>England Rugby Players’ Association (RPA)</td>
<td>261</td>
<td>49</td>
<td>10.34</td>
<td>19.2</td>
</tr>
<tr>
<td>Irish Rugby Union Players’ Association (IRUPA)</td>
<td>29</td>
<td>13</td>
<td>44.83</td>
<td>5.1</td>
</tr>
<tr>
<td>New Zealand Rugby Union Players’ Association (NZRPA)</td>
<td>250</td>
<td>65</td>
<td>24.40</td>
<td>25.5</td>
</tr>
<tr>
<td>Other (IRB Members)</td>
<td>7</td>
<td>7</td>
<td>100.00</td>
<td>2.8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>961</td>
<td>255</td>
<td>26.53</td>
<td></td>
</tr>
</tbody>
</table>

#### 3.4.1 Demographics and career related information

Demographic and career related data were grouped and then analysed for forwards and backs (Table 3.3). A one way ANOVA indicated no significant difference between the forwards and backs for current age, $F_{(1, 194)} = 0.44, p= 0.51$, age at retirement, $F_{(1, 190)} = 1.53, p= 0.22$, or years of professional rugby, $F_{(1, 190)} = 0.59, p= 0.44$. However, the self-reported anthropometric variables revealed that the forwards were significantly taller than the backs, $F_{(1, 190)} = 62.48, p< 0.00$, and were heavier during their careers, $F_{(1, 192)} = 333.76, p< 0.00$ and currently, $F_{(1, 193)} = 117.34, p< 0.00$. Mean and standard deviations for the demographic and rugby career information is described for each playing position (Table 3.4).
Table 3.3: Analysis of variance examining the anthropometric characteristics and rugby career information for forwards and backs (n= 195)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Position</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>Lower</th>
<th>Upper</th>
<th>Min</th>
<th>Max</th>
<th>F-value</th>
<th>p</th>
<th>$\eta^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>Forwards</td>
<td>122</td>
<td>37.99</td>
<td>5.56</td>
<td>37.00</td>
<td>38.99</td>
<td>25.00</td>
<td>57.00</td>
<td>0.44</td>
<td>0.51</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td>Backs</td>
<td>73</td>
<td>37.45</td>
<td>5.48</td>
<td>36.17</td>
<td>38.73</td>
<td>26.00</td>
<td>53.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Combined</td>
<td>195</td>
<td>37.79</td>
<td>5.52</td>
<td>37.01</td>
<td>38.57</td>
<td>25.00</td>
<td>57.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Retirement age (yrs)</td>
<td>Forwards</td>
<td>121</td>
<td>32.88</td>
<td>4.03</td>
<td>32.15</td>
<td>33.60</td>
<td>22.00</td>
<td>47.00</td>
<td>1.53</td>
<td>0.22</td>
<td>0.008</td>
</tr>
<tr>
<td></td>
<td>Backs</td>
<td>71</td>
<td>32.14</td>
<td>3.88</td>
<td>31.22</td>
<td>33.06</td>
<td>26.00</td>
<td>47.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Combined</td>
<td>192</td>
<td>32.60</td>
<td>3.98</td>
<td>32.04</td>
<td>33.17</td>
<td>22.00</td>
<td>47.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Years of professional rugby played</td>
<td>Forwards</td>
<td>120</td>
<td>8.58</td>
<td>3.83</td>
<td>7.88</td>
<td>9.2672</td>
<td>1.00</td>
<td>16.00</td>
<td>0.59</td>
<td>0.44</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td>Backs</td>
<td>72</td>
<td>9.03</td>
<td>4.14</td>
<td>8.05</td>
<td>10.00</td>
<td>1.00</td>
<td>16.00</td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td>Combined</td>
<td>192</td>
<td>8.74</td>
<td>3.95</td>
<td>8.18</td>
<td>9.30</td>
<td>1.00</td>
<td>16.00</td>
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</tr>
<tr>
<td>Playing weight (kg)</td>
<td>Forwards</td>
<td>122</td>
<td>109.97</td>
<td>6.89</td>
<td>108.73</td>
<td>111.20</td>
<td>93.64</td>
<td>126.00</td>
<td>0.01*</td>
<td>0.64</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Backs</td>
<td>72</td>
<td>91.08</td>
<td>7.06</td>
<td>89.42</td>
<td>92.74</td>
<td>78.00</td>
<td>110.00</td>
<td></td>
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<tr>
<td></td>
<td>Combined</td>
<td>194</td>
<td>102.96</td>
<td>11.48</td>
<td>101.33</td>
<td>104.58</td>
<td>78.00</td>
<td>126.00</td>
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<td></td>
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<tr>
<td>Current weight (kg)</td>
<td>Forwards</td>
<td>122</td>
<td>109.28</td>
<td>12.36</td>
<td>107.07</td>
<td>111.49</td>
<td>88.18</td>
<td>155.00</td>
<td>0.01*</td>
<td>0.38</td>
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<td>Backs</td>
<td>73</td>
<td>91.70</td>
<td>8.11</td>
<td>89.81</td>
<td>93.60</td>
<td>75.00</td>
<td>110.00</td>
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<td></td>
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<tr>
<td></td>
<td>Combined</td>
<td>195</td>
<td>102.70</td>
<td>13.87</td>
<td>100.74</td>
<td>104.66</td>
<td>75.00</td>
<td>155.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height (cm)</td>
<td>Forwards</td>
<td>122</td>
<td>189.10</td>
<td>7.04</td>
<td>187.84</td>
<td>190.36</td>
<td>175.00</td>
<td>210.00</td>
<td>62.48</td>
<td>0.01*</td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td>Backs</td>
<td>73</td>
<td>181.51</td>
<td>5.45</td>
<td>180.24</td>
<td>182.78</td>
<td>170.00</td>
<td>194.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Combined</td>
<td>195</td>
<td>186.26</td>
<td>7.45</td>
<td>185.21</td>
<td>187.31</td>
<td>170.00</td>
<td>210.00</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Denotes statistical significance $p< 0.05$
### Table 3.4: Anthropometric data based on most common playing position

<table>
<thead>
<tr>
<th>Positions</th>
<th>#</th>
<th>Mean (Age yrs)</th>
<th>SD (Age yrs)</th>
<th>Mean (Age at retirement yrs)</th>
<th>SD (Age at retirement yrs)</th>
<th>Mean (Playing weight kg)</th>
<th>SD (Playing weight kg)</th>
<th>Mean (Current weight kg)</th>
<th>SD (Current weight kg)</th>
<th>Mean (Height cm)</th>
<th>SD (Height cm)</th>
<th>Mean (Years of professional rugby yrs)</th>
<th>SD (Years of professional rugby yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forwards</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loose-head prop</td>
<td>1</td>
<td>36.44</td>
<td>5.28</td>
<td>32.19</td>
<td>3.10</td>
<td>114.08</td>
<td>5.13</td>
<td>115.78</td>
<td>12.74</td>
<td>183.60</td>
<td>4.84</td>
<td>8.00</td>
<td>5.05</td>
</tr>
<tr>
<td>Hooker</td>
<td>2</td>
<td>38.50</td>
<td>5.06</td>
<td>32.21</td>
<td>3.66</td>
<td>104.56</td>
<td>5.72</td>
<td>101.63</td>
<td>9.97</td>
<td>182.21</td>
<td>2.42</td>
<td>7.71</td>
<td>4.03</td>
</tr>
<tr>
<td>Tight-head prop</td>
<td>3</td>
<td>37.27</td>
<td>6.90</td>
<td>33.73</td>
<td>5.42</td>
<td>116.58</td>
<td>4.93</td>
<td>112.38</td>
<td>10.76</td>
<td>182.21</td>
<td>4.26</td>
<td>7.93</td>
<td>3.59</td>
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<td>Second row</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 or 5</td>
<td>4</td>
<td>38.96</td>
<td>4.76</td>
<td>33.00</td>
<td>3.67</td>
<td>113.86</td>
<td>5.46</td>
<td>114.64</td>
<td>11.95</td>
<td>197.55</td>
<td>3.39</td>
<td>8.64</td>
<td>3.85</td>
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<td>Flankers</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 or 7</td>
<td>6</td>
<td>37.67</td>
<td>5.93</td>
<td>32.10</td>
<td>7.51</td>
<td>104.16</td>
<td>4.02</td>
<td>102.95</td>
<td>11.68</td>
<td>188.48</td>
<td>4.59</td>
<td>9.32</td>
<td>3.10</td>
</tr>
<tr>
<td>Number 8</td>
<td>8</td>
<td>38.58</td>
<td>5.79</td>
<td>32.53</td>
<td>4.25</td>
<td>108.70</td>
<td>5.37</td>
<td>109.09</td>
<td>9.61</td>
<td>192.80</td>
<td>3.79</td>
<td>9.00</td>
<td>3.87</td>
</tr>
<tr>
<td>Backs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scrum-half</td>
<td>9</td>
<td>37.64</td>
<td>6.21</td>
<td>31.79</td>
<td>3.21</td>
<td>84.06</td>
<td>4.08</td>
<td>85.69</td>
<td>6.66</td>
<td>176.82</td>
<td>4.60</td>
<td>8.57</td>
<td>4.13</td>
</tr>
<tr>
<td>Fly-half</td>
<td>10</td>
<td>37.80</td>
<td>3.82</td>
<td>28.60</td>
<td>10.92</td>
<td>85.68</td>
<td>4.61</td>
<td>86.31</td>
<td>4.19</td>
<td>179.37</td>
<td>3.88</td>
<td>8.90</td>
<td>5.97</td>
</tr>
<tr>
<td>Wings</td>
<td>11</td>
<td>37.67</td>
<td>7.24</td>
<td>30.73</td>
<td>9.74</td>
<td>94.53</td>
<td>5.52</td>
<td>96.44</td>
<td>6.47</td>
<td>182.90</td>
<td>4.26</td>
<td>10.20</td>
<td>4.02</td>
</tr>
<tr>
<td>Centres</td>
<td>12</td>
<td>37.00</td>
<td>5.68</td>
<td>31.17</td>
<td>4.37</td>
<td>94.72</td>
<td>6.68</td>
<td>93.82</td>
<td>8.75</td>
<td>182.98</td>
<td>5.37</td>
<td>7.78</td>
<td>3.50</td>
</tr>
<tr>
<td>Full-back</td>
<td>15</td>
<td>37.55</td>
<td>2.84</td>
<td>33.73</td>
<td>2.97</td>
<td>92.09</td>
<td>5.49</td>
<td>93.36</td>
<td>6.85</td>
<td>184.45</td>
<td>5.63</td>
<td>10.90</td>
<td>3.11</td>
</tr>
</tbody>
</table>
The sample population consisted of 92 respondents from the southern hemisphere and 103 from the northern. The majority (178 out of 195) of an individual’s professional career was spent in their country of origin (Figure 3.4). The largest number of players playing the majority of their professional career in another country was five, from the England Rugby Players’ Association. Examination of the level of rugby played determined that 70.3% (n = 137) played at an international level, 23.6% (n = 46) Super Rugby/Heineken Cup, 3.6% (n = 7) played on national teams, and 2.5% (n = 5) had played at provincial or state level. For the cohort examined, the mean reported age at retirement was 37.79 ± 5.52 years, and the most frequency cited year of retirement was 2008 (n = 20) and the least 1996 (n = 2). Figure 3.5 illustrates the year that the respondents retired from professional rugby.

Figure 3.4: Players’ Association/ Rugby Union Affiliations

Figure 3.5: Year respondents retired from professional rugby
3.4.2  Self-reported injury frequency and occurrence over a career

3.4.2.1  Most frequent anatomical sites of injury

Analysis of the injured body areas revealed that the neck was ranked 4\textsuperscript{th} most frequent (Table 3.5). When asked to recall the events that surrounded the injury, with the opportunity to select more than one option, the following were reported: (a) playing games \(n= 178\), (b) rugby practice \(n= 47\), (c) fitness training \(n= 12\), and (d) weight training \(n=10\). Cross tabulation was conducted to compare the results for participants \((n= 71)\) that highlighted the neck as a frequent area of injury. Most neck injuries were attributed to ‘playing games’ \((n= 64)\) followed by ‘rugby practice’ \((n= 19)\).
Table 3.5: Weighted ranking scores from the most frequently sustained injuries during game play or training for rugby

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Area</th>
<th>Weighted ranking score</th>
<th>Ranking cont.</th>
<th>Area</th>
<th>Weighted ranking score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Right knee</td>
<td>310</td>
<td>19</td>
<td>Left calf</td>
<td>48</td>
</tr>
<tr>
<td>2</td>
<td>Right shoulder</td>
<td>289</td>
<td>20</td>
<td>Groin</td>
<td>47</td>
</tr>
<tr>
<td>3</td>
<td>Left shoulder</td>
<td>277</td>
<td>21</td>
<td>Right foot</td>
<td>47</td>
</tr>
<tr>
<td>4</td>
<td>Neck</td>
<td>274</td>
<td>22</td>
<td>Left hip</td>
<td>45</td>
</tr>
<tr>
<td>5</td>
<td>Left knee</td>
<td>264</td>
<td>23</td>
<td>Ribs/chest</td>
<td>41</td>
</tr>
<tr>
<td>6</td>
<td>Facial and/or scalp injuries</td>
<td>250</td>
<td>24</td>
<td>Right achilles tendon</td>
<td>39</td>
</tr>
<tr>
<td>7</td>
<td>Right ankle</td>
<td>187</td>
<td>25</td>
<td>Right elbow</td>
<td>35</td>
</tr>
<tr>
<td>8</td>
<td>Concussion</td>
<td>160</td>
<td>26</td>
<td>Left achilles tendon</td>
<td>30</td>
</tr>
<tr>
<td>9</td>
<td>Low back</td>
<td>156</td>
<td>27</td>
<td>Right quadriceps/thigh</td>
<td>24</td>
</tr>
<tr>
<td>10</td>
<td>Left ankle</td>
<td>147</td>
<td>28</td>
<td>Left quadriceps/thigh</td>
<td>22</td>
</tr>
<tr>
<td>11</td>
<td>Thoracic spine</td>
<td>143</td>
<td>29</td>
<td>Left elbow</td>
<td>19</td>
</tr>
<tr>
<td>12</td>
<td>Left hand, thumb or fingers</td>
<td>125</td>
<td>30</td>
<td>Right shin</td>
<td>16</td>
</tr>
<tr>
<td>13</td>
<td>Right hand, thumb or fingers</td>
<td>97</td>
<td>31</td>
<td>Right wrist</td>
<td>14</td>
</tr>
<tr>
<td>14</td>
<td>Right hamstring</td>
<td>90</td>
<td>32</td>
<td>Abdomen</td>
<td>14</td>
</tr>
<tr>
<td>15</td>
<td>Left hamstring</td>
<td>82</td>
<td>33</td>
<td>Right forearm</td>
<td>11</td>
</tr>
<tr>
<td>16</td>
<td>Right hip</td>
<td>70</td>
<td>34</td>
<td>Left wrist</td>
<td>7</td>
</tr>
<tr>
<td>17</td>
<td>Left foot</td>
<td>58</td>
<td>35</td>
<td>Left forearm</td>
<td>6</td>
</tr>
<tr>
<td>18</td>
<td>Right calf</td>
<td>58</td>
<td>36</td>
<td>Left shin</td>
<td>5</td>
</tr>
</tbody>
</table>
Respondents were asked “is there one injury that stands out in your career that you would like to tell us about?” Answers were provided by 173 of the 195 respondents. These were grouped and categorized based on primary body part discussed: 40 related specifically to the neck, 28 to knees, 19 to concussions, 14 to ankles, 13 to shoulders, 11 had a multiple complaints, 10 to both the lumbar spine and hip, 5 to the leg, 4 to internal organs damage or contracting an infection related to a laceration, 3 to arm, 2 to the ribs, and 1 to both the groin and the foot. The quotes relating specifically to injuries sustained by the neck were examined for common themes (Table 3.6). The following themes were identified: (a) long-term health impact, (b) career ending injury, (c) multiple injuries to body segments including the neck, (d) injury to the neck predisposed them to future injuries, and (e) neck injury.
Table 3.6: Examination of common themes in the open ended question* relating to ‘an injury that stood out’ in the participant’s career

<table>
<thead>
<tr>
<th>Theme</th>
<th>Example of primary theme</th>
<th>Frequency</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long-term health impact</td>
<td>I had a disc removed from C6/C7 very early in my career and had it successfully treated but it has had long term effects in terms of arthritic stiffness and pain. (P 178)</td>
<td>10</td>
<td>27.5%</td>
</tr>
<tr>
<td></td>
<td>Neck injury - serious neck strain (1987), disc prolapse C6-C7 vertebrae (2001) - still feeling effects thereof and some periodic discomfort. Requires on-going self-management (self-massage, stretching and strengthening) and some physio and massage. (P 204)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>My neck has consistently given me problems throughout my career and currently. I have a number of on going issues that I'm told require surgery sooner rather than later. (P 209)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Career ending injury</td>
<td>Long standing neck degeneration injury which forced me to retire due to constant pain and inability to play pro rugby. (P 128)</td>
<td>10</td>
<td>25.0%</td>
</tr>
<tr>
<td></td>
<td>Final injury that finished my career was a prolapsed disc between C5 &amp; C6. It prolapsed inwards and nearly severed my spinal column. Sustained during a game but not diagnosed for 2 months in which I had continued to train and play. (P 173)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multiple injuries to body segments including the neck</td>
<td>Dislocated ankle broken tibia and fibula. Broken c1 vertebrae. (P 082)</td>
<td>5</td>
<td>12.5%</td>
</tr>
<tr>
<td></td>
<td>Game &amp; training injuries: Separated shoulder, continual 'stingers' emanating from the right shoulder, sprained left knee, broken finger right hand, sprained ankle, many stitches to head and face, one noticeable concussion. (P 075)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injury to the neck predisposed them to future injuries</td>
<td>Twice had herniated discs in neck that resulted in short term (5 months) loss of muscle function in right arm/hand first: C4-C5 Second:C6-C7. (P 220)</td>
<td>3</td>
<td>7.5%</td>
</tr>
<tr>
<td></td>
<td>Neck hyper flexion in 1987 as a youth - still feel effects now. Very close to breaking neck and through career have suffered a number of related injuries around the same site (C6-C7). Have osteophytes impinging on nerves and creates ongoing NP. (P 097)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Neck, herniated disk twice. (P 045)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neck injury</td>
<td>I have a plate and 4 screws in my neck c6 c7 results from a ruck. (P 232)</td>
<td>11</td>
<td>27.5%</td>
</tr>
<tr>
<td></td>
<td>Cervical spine (C6-C7) disc herniation. (P 199)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hyper flexion of neck requiring hospitalisation and brace. (P 037)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Responses presented verbatim
3.4.2.2 Surgical interventions

Participants were asked to indicate body areas (Table 3.7) that required surgery during their rugby career due to injuries sustained while playing or training for rugby. The neck ranked 9th in frequency for surgical interventions. Of the 18 neck injuries that required surgery, 13 were sustained while ‘playing games’, three during ‘rugby practice’ and the remainder during ‘fitness and weight training’.

Table 3.7: Total number of surgeries based on body region

<table>
<thead>
<tr>
<th>Body region</th>
<th>Total number of surgeries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee</td>
<td>284</td>
</tr>
<tr>
<td>Shoulder</td>
<td>99</td>
</tr>
<tr>
<td>Ankle</td>
<td>87</td>
</tr>
<tr>
<td>Hand, thumb or fingers</td>
<td>62</td>
</tr>
<tr>
<td>Hip</td>
<td>39</td>
</tr>
<tr>
<td>Groin</td>
<td>31</td>
</tr>
<tr>
<td>Elbow</td>
<td>30</td>
</tr>
<tr>
<td>Foot</td>
<td>29</td>
</tr>
<tr>
<td>Neck</td>
<td>18</td>
</tr>
<tr>
<td>Wrist</td>
<td>17</td>
</tr>
<tr>
<td>Shin</td>
<td>15</td>
</tr>
<tr>
<td>Achilles tendon</td>
<td>12</td>
</tr>
<tr>
<td>Low back</td>
<td>10</td>
</tr>
<tr>
<td>Forearm</td>
<td>10</td>
</tr>
<tr>
<td>Abdomen</td>
<td>8</td>
</tr>
<tr>
<td>Thoracic spine</td>
<td>7</td>
</tr>
<tr>
<td>Ribs/chest</td>
<td>4</td>
</tr>
<tr>
<td>Quadriceps/thigh</td>
<td>2</td>
</tr>
<tr>
<td>Hamstring</td>
<td>2</td>
</tr>
<tr>
<td>Calf</td>
<td>2</td>
</tr>
<tr>
<td>Total number of surgeries</td>
<td>768</td>
</tr>
</tbody>
</table>
3.4.3 Neck injuries sustained during their rugby career and the prescription of neck exercises following injury

Participants were asked if they had sustained a neck injury during their rugby careers, 144 of the 183 (78.7%) indicated they had. Of these 18.8% (n = 27) frequently, 51.4% (n = 74) occasionally, or 29.9% (n = 43) never performed neck specific exercises as part of a training routine, prior to their neck injury. Following their neck injury 53.3% (n = 104) were prescribed neck specific exercises by a medical professional, and 97.4% of these respondents indicated that they completed the neck exercises as prescribed. The final question for participants who had sustained a neck injury (n = 144) enquired as to whether or not the individual continued with the neck exercises once their injury had resolved. Nearly half (47.2%, n = 68) replied ‘yes’, 38.2% (n = 55) stated ‘no’, and the remainder indicated that the neck injury/NP never resolved 14.6% (n = 21).

3.4.4 Current pain and stiffness from rugby related injuries

3.4.4.1 Current pain

The neck was the top ranked area of current pain for the 195 respondents (Table 3.8). Respondents were asked, “if you are typically experiencing pain, what would you attribute the majority of this pain to.” Most respondents highlighted ‘playing and training for rugby’ (n = 63, 34.6%) as the activity responsible for their current pain. This was followed by ‘aging’ (n = 47, 25.8%), refer to Table 3.9.
### Table 3.8: Top ranked body regions of self-reported current pain

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Area</th>
<th>Weighted ranking scores</th>
<th>Ranking cont.</th>
<th>Area</th>
<th>Weighted ranking scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Neck</td>
<td>334</td>
<td>18</td>
<td>Groin</td>
<td>28</td>
</tr>
<tr>
<td>2</td>
<td>Low back</td>
<td>313</td>
<td>19</td>
<td>Left calf</td>
<td>23</td>
</tr>
<tr>
<td>3</td>
<td>Right knee</td>
<td>293</td>
<td>20</td>
<td>Right achilles tendon</td>
<td>22</td>
</tr>
<tr>
<td>4</td>
<td>Left knee</td>
<td>267</td>
<td>21</td>
<td>Right hamstring</td>
<td>16</td>
</tr>
<tr>
<td>5</td>
<td>Thoracic spine</td>
<td>224</td>
<td>22</td>
<td>Right calf</td>
<td>16</td>
</tr>
<tr>
<td>6</td>
<td>Right shoulder</td>
<td>141</td>
<td>23</td>
<td>Right wrist</td>
<td>15</td>
</tr>
<tr>
<td>7</td>
<td>Left shoulder</td>
<td>131</td>
<td>24</td>
<td>Left wrist</td>
<td>14</td>
</tr>
<tr>
<td>8</td>
<td>Left ankle</td>
<td>114</td>
<td>25</td>
<td>Right elbow</td>
<td>12</td>
</tr>
<tr>
<td>9</td>
<td>Right hip</td>
<td>110</td>
<td>26</td>
<td>Right quadriceps/thigh</td>
<td>12</td>
</tr>
<tr>
<td>10</td>
<td>Left hip</td>
<td>97</td>
<td>27</td>
<td>Left hamstring</td>
<td>12</td>
</tr>
<tr>
<td>11</td>
<td>Right ankle</td>
<td>83</td>
<td>28</td>
<td>Left quadriceps/thigh</td>
<td>8</td>
</tr>
<tr>
<td>12</td>
<td>Right foot</td>
<td>55</td>
<td>29</td>
<td>Right shin</td>
<td>7</td>
</tr>
<tr>
<td>13</td>
<td>Left foot</td>
<td>49</td>
<td>30</td>
<td>Ribs/chest</td>
<td>6</td>
</tr>
<tr>
<td>14</td>
<td>Right hand, thumb or fingers</td>
<td>36</td>
<td>31</td>
<td>Left forearm</td>
<td>3</td>
</tr>
<tr>
<td>15</td>
<td>Left elbow</td>
<td>31</td>
<td>32</td>
<td>Abdomen</td>
<td>2</td>
</tr>
<tr>
<td>16</td>
<td>Left hand, thumb or fingers</td>
<td>29</td>
<td>33</td>
<td>Left shin</td>
<td>2</td>
</tr>
<tr>
<td>17</td>
<td>Right achilles tendon</td>
<td>29</td>
<td>34</td>
<td>Right forearm</td>
<td>0</td>
</tr>
</tbody>
</table>
**Table 3.9: What activities respondents attributed their current pain to**

<table>
<thead>
<tr>
<th>Activities pain is attributed to</th>
<th>Frequency</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Playing rugby</td>
<td>20</td>
<td>11.0</td>
</tr>
<tr>
<td>Training for rugby</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>Both playing and training for rugby</td>
<td>63</td>
<td>34.6</td>
</tr>
<tr>
<td>Gym or fitness training</td>
<td>6</td>
<td>3.3</td>
</tr>
<tr>
<td>Work</td>
<td>4</td>
<td>2.2</td>
</tr>
<tr>
<td>Recreation</td>
<td>15</td>
<td>8.2</td>
</tr>
<tr>
<td>Aging</td>
<td>47</td>
<td>25.8</td>
</tr>
<tr>
<td>Other</td>
<td>2</td>
<td>1.1</td>
</tr>
<tr>
<td>I cannot attribute this pain to anything</td>
<td>24</td>
<td>13.2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>182</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>

3.4.4.2 Current stiffness

Participants were asked to describe their current areas of stiffness (rank and identify up to 5 areas of current stiffness). Of the 195 individuals that responded to this question the low back, followed by the neck were the most frequently selected (Table 3.10). Respondents mainly attributed this stiffness to ‘playing and training for rugby’ 30.5% \((n= 54)\) and ‘aging’ 28.8% \((n= 51)\). In contrast to the pain results, ‘playing rugby’ was more commonly cited 11.3% \((n= 20)\), and being unable to attribute stiffness to anything in particular dropped in frequency (Table 3.11).
<table>
<thead>
<tr>
<th>Ranking</th>
<th>Area</th>
<th>Weighted ranking score</th>
<th>Ranking cont.</th>
<th>Area</th>
<th>Weighted ranking score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Low back</td>
<td>397</td>
<td>18</td>
<td>Right quad/thigh</td>
<td>31</td>
</tr>
<tr>
<td>2</td>
<td>Neck</td>
<td>359</td>
<td>19</td>
<td>Right achilles</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>Thoracic spine</td>
<td>316</td>
<td>20</td>
<td>Left quad/thigh</td>
<td>26</td>
</tr>
<tr>
<td>4</td>
<td>Right knee</td>
<td>219</td>
<td>21</td>
<td>Right hand, thumb or fingers</td>
<td>24</td>
</tr>
<tr>
<td>5</td>
<td>Left knee</td>
<td>187</td>
<td>22</td>
<td>Left hand, thumb or fingers</td>
<td>23</td>
</tr>
<tr>
<td>6</td>
<td>Right hip</td>
<td>161</td>
<td>23</td>
<td>Left foot</td>
<td>22</td>
</tr>
<tr>
<td>7</td>
<td>Left hip</td>
<td>126</td>
<td>24</td>
<td>Right foot</td>
<td>21</td>
</tr>
<tr>
<td>8</td>
<td>Right shoulder</td>
<td>112</td>
<td>25</td>
<td>Right wrist</td>
<td>11</td>
</tr>
<tr>
<td>9</td>
<td>Left shoulder</td>
<td>93</td>
<td>26</td>
<td>Left wrist</td>
<td>7</td>
</tr>
<tr>
<td>10</td>
<td>Left ankle</td>
<td>73</td>
<td>27</td>
<td>Ribs/chest</td>
<td>6</td>
</tr>
<tr>
<td>11</td>
<td>Right ankle</td>
<td>67</td>
<td>28</td>
<td>Abdomen</td>
<td>6</td>
</tr>
<tr>
<td>12</td>
<td>Left hamstring</td>
<td>53</td>
<td>29</td>
<td>Right shin</td>
<td>3</td>
</tr>
<tr>
<td>13</td>
<td>Right hamstring</td>
<td>43</td>
<td>30</td>
<td>Left shin</td>
<td>2</td>
</tr>
<tr>
<td>14</td>
<td>Left calf</td>
<td>40</td>
<td>31</td>
<td>Right elbow</td>
<td>1</td>
</tr>
<tr>
<td>15</td>
<td>Left achilles</td>
<td>35</td>
<td>32</td>
<td>Left elbow</td>
<td>1</td>
</tr>
<tr>
<td>16</td>
<td>Right calf</td>
<td>33</td>
<td>33</td>
<td>Right forearm</td>
<td>0</td>
</tr>
<tr>
<td>17</td>
<td>Groin</td>
<td>31</td>
<td>34</td>
<td>Left forearm</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 3.11: What activities respondents attributed their current stiffness to ($n=177$)

<table>
<thead>
<tr>
<th>Activities stiffness is attributed to</th>
<th>Frequency</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Playing rugby</td>
<td>20</td>
<td>11.3</td>
</tr>
<tr>
<td>Training for rugby</td>
<td>7</td>
<td>4.0</td>
</tr>
<tr>
<td>Both playing and training for rugby</td>
<td>54</td>
<td>30.5</td>
</tr>
<tr>
<td>Gym or fitness training</td>
<td>5</td>
<td>2.8</td>
</tr>
<tr>
<td>Work</td>
<td>6</td>
<td>3.4</td>
</tr>
<tr>
<td>Recreation</td>
<td>17</td>
<td>9.6</td>
</tr>
<tr>
<td>Aging</td>
<td>51</td>
<td>28.8</td>
</tr>
<tr>
<td>Combo</td>
<td>1</td>
<td>0.6</td>
</tr>
<tr>
<td>Other</td>
<td>2</td>
<td>1.1</td>
</tr>
<tr>
<td>I cannot attribute this pain to anything</td>
<td>14</td>
<td>7.9</td>
</tr>
<tr>
<td>Total</td>
<td>177</td>
<td>100.0</td>
</tr>
</tbody>
</table>

3.4.5 Current neck pain and/or neck stiffness

For this question it was decided to incorporate both neck pain and neck stiffness as one global variable. Of the 174 that responded to the question on current NP and/or NS, 79.9% ($n=139$) indicated that they were experiencing one or both of these symptoms. For those that were currently experiencing NP, 90.65% indicated that they had sustained a neck injury during their careers. Of these 88.6% ($n=124$) related this to ‘training for or playing rugby’. Some could not link their NP with rugby’ (3.6%, $n=5$) and others were ‘unsure’ 7.9% ($n=11$). The most common response for the intensity and frequency of NP and/or NS symptoms was ‘occasionally mild’ for many (33.1%) or ‘occasionally moderate’ (25.2%). A more concerning factor was that 27.4% of individuals were continually experiencing some form of NP and/or NS of varying severity (Table 3.12). When asked to elaborate on when symptoms were worse the most frequent response was ‘in the morning when I wake up’ ($n=74$, 54.8%), followed by ‘at work’ ($n=37$, 27.4%), and ‘when sleeping’ ($n=29$, 21.5%). For 28.9% ($n=39$) NP and/or NS occurred at ‘other’ times not covered in the question. Activities that the participants reported as most symptomatic or aggravating were ‘sleeping/getting up in the morning’ 48.9% ($n=64$), ‘sitting’ 38.9% ($n=51$), or ‘when driving’ 30.5% ($n=40$). The most sought form of treatment was from physiotherapists (21.0%), massage therapists (18.6%), medical practitioners (15.4%) and chiropractors/osteopaths (15.2%). In contrast 11.1% of individuals did not seek treatment for their NP and/or NS (Figure 3.6).
Table 3.12: Self-reported intensity and frequency of the respondents’ neck pain (NP) and/or neck stiffness (NS)

<table>
<thead>
<tr>
<th>Severity of NP and/or NS</th>
<th>Frequency</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant and severe</td>
<td>3</td>
<td>2.2</td>
</tr>
<tr>
<td>Constant but moderate</td>
<td>21</td>
<td>15.1</td>
</tr>
<tr>
<td>Constant but mild</td>
<td>14</td>
<td>10.1</td>
</tr>
<tr>
<td>Occasionally severe</td>
<td>13</td>
<td>9.4</td>
</tr>
<tr>
<td>Occasionally moderate</td>
<td>35</td>
<td>25.2</td>
</tr>
<tr>
<td>Occasionally mild</td>
<td>46</td>
<td>33.1</td>
</tr>
<tr>
<td>Other</td>
<td>7</td>
<td>5.0</td>
</tr>
<tr>
<td>Total</td>
<td>139</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Figure 3.6: Professionals who were seen for treatment for neck pain and/or stiffness

3.4.6 Neck Disability Index

The NDI was completed by 169 participants (86.7%). Forwards did not differ significantly from backs, $F_{(1,164)} = 0.79, p = 0.38$, in their total NDI score (Table 3.13). Examination of the combined NDI total scores for each participant revealed that 3.0% ($n=5$) reported severe disability related to their NP, 16.8% ($n=28$) moderate disability, 28.1% ($n=47$) mild disability, and 51.1% ($n=86$) reported no disability. When each of the components in the questionnaire were examined for the two positional groups, the highest level of disability was recorded for ‘pain intensity’ for the forwards and ‘recreation’ for the backs. In contrast, both groups reported the lowest levels of disability for ‘personal care’ and ‘sleeping’ (Table 3.14). As the data were negatively skewed, a non-parametric Mann-Whitney U test was conducted.
to explore the difference between the responses for the forwards and backs. Single direction Monte Carlo significance level was isolated for ‘pain intensity’, \( U = 2832.00, p = 0.04 \), indicating that the forwards reported higher levels of NP than the backs. Although the ‘lifting’ (\( U = 2892.00, p = 0.06 \)) and ‘driving’ (\( U = 2799.50, p = 0.06 \)) components of the questionnaire just failed to reach significance, they had a similar trend to the ‘pain intensity’ with forwards reporting higher disability levels relating to NP than the backs.

**Table 3.13**: A comparison of the total Neck Disability Index (NDI) scores for the forwards and backs. Scores ranged from 0= no disability to 50= maximum disability.

<table>
<thead>
<tr>
<th></th>
<th>Position</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>Lower</th>
<th>Upper</th>
<th>Min</th>
<th>Max</th>
<th>F-value</th>
<th>p</th>
<th>( \eta^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDI total score</td>
<td>Forwards</td>
<td>105</td>
<td>7.41</td>
<td>7.46</td>
<td>5.97</td>
<td>8.85</td>
<td>0</td>
<td>30</td>
<td>0.79</td>
<td>0.38</td>
<td>0.01’</td>
</tr>
<tr>
<td></td>
<td>Backs</td>
<td>64</td>
<td>6.34</td>
<td>7.43</td>
<td>4.44</td>
<td>8.25</td>
<td>0</td>
<td>28</td>
<td>0.53</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Combined</td>
<td>169</td>
<td>7.02</td>
<td>7.44</td>
<td>5.88</td>
<td>8.16</td>
<td>0</td>
<td>30</td>
<td>0.79</td>
<td>0.38</td>
<td></td>
</tr>
</tbody>
</table>

**Table 3.14**: Individual item scores for the Neck Disability Index (NDI) for the forwards and backs.

<table>
<thead>
<tr>
<th>Items</th>
<th>Forwards (n=105)</th>
<th>Backs (n=64)</th>
<th>Combined (n=169)</th>
<th>Mann-Whitney U</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>1 Pain intensity</td>
<td>1.17</td>
<td>1.21</td>
<td>0.83</td>
<td>1.19</td>
<td>1.00</td>
</tr>
<tr>
<td>2 Personal care</td>
<td>0.15</td>
<td>0.60</td>
<td>0.05</td>
<td>0.38</td>
<td>0.10</td>
</tr>
<tr>
<td>3 Lifting</td>
<td>0.53</td>
<td>1.04</td>
<td>0.31</td>
<td>0.85</td>
<td>0.42</td>
</tr>
<tr>
<td>4 Work</td>
<td>0.95</td>
<td>1.30</td>
<td>0.90</td>
<td>1.23</td>
<td>0.93</td>
</tr>
<tr>
<td>5 Headaches</td>
<td>1.00</td>
<td>1.21</td>
<td>0.92</td>
<td>1.28</td>
<td>0.96</td>
</tr>
<tr>
<td>6 Concentration</td>
<td>0.54</td>
<td>1.07</td>
<td>0.59</td>
<td>1.07</td>
<td>0.57</td>
</tr>
<tr>
<td>7 Sleeping</td>
<td>0.24</td>
<td>0.78</td>
<td>0.30</td>
<td>0.84</td>
<td>0.27</td>
</tr>
<tr>
<td>8 Driving</td>
<td>0.99</td>
<td>1.20</td>
<td>0.69</td>
<td>1.06</td>
<td>0.84</td>
</tr>
<tr>
<td>9 Reading</td>
<td>0.94</td>
<td>1.22</td>
<td>0.74</td>
<td>1.21</td>
<td>0.84</td>
</tr>
<tr>
<td>10 Recreation</td>
<td>0.88</td>
<td>1.18</td>
<td>1.00</td>
<td>1.38</td>
<td>0.94</td>
</tr>
<tr>
<td>Total Score</td>
<td>7.41</td>
<td>7.46</td>
<td>6.34</td>
<td>7.43</td>
<td>6.88</td>
</tr>
</tbody>
</table>

### 3.5 Discussion

There are a number of studies that have documented the frequency of neck injuries in actively playing athletes involved in rugby [20, 24, 29, 30, 35, 36, 111, 140, 231, 245, 255, 256].
However, the long-term consequences of these injuries and the impact participation in rugby has on the neck is unknown. This is the first study to explore the impact participation in a collision based sport has on the necks of retired athletes. This retrospective survey provided a unique opportunity to explore and investigate the self-reported health status of a sample of former professional rugby players from multiple rugby playing nations. The neck was the 4th most frequently injured body region with the majority of injuries sustained during games and the 9th most common area that required surgery intervention. In terms of current health status, the neck was the most commonly cited area of pain and the second most common area of stiffness. Ninety one percent (91%) of respondents reporting NP and/or NS had a history of neck injury in the sport. The mean total NDI score for the forwards was 7.41 ± 7.46 and backs 6.34 ± 7.43, with just under half of the study population reporting some form of disability relating to their NP. Indicating that for these individuals NP affected their ability to complete activities of daily living. Thus suggesting that the long-term impact of participating in professional rugby is considerable, with many respondents reporting continued pain and stiffness in this region well after their professional career had ended.

3.5.1 Response rates and survey cohort demographics

The most frequently cited methodology for exploring the long-term health status of retired players is the retrospective survey (102-107, 113, 257-268). In the current study the response rates from each of the respective Players’ Associations/Unions ranged from 10-44%, with an overall response rate of 26%. The response rate in the current study is lower than the response rates reported in postal surveys 37-55% of professional football players (101, 102, 268) and the 69.3% in retired NFL players (105, 106, 269). The lower response rate in the current study may reflect the fact that only the online method of contact was used, while research with the retired NFL players used postal surveys and follow-up phone interviews. Research examining varying modes of survey contact have also reported low response rates with online surveys, and improved rates when multiple modes of contact are used (246, 251, 270). Despite the wealth of information regarding the use of online surveys (241, 247, 252), to the best of the candidate’s knowledge there is no published literature that has used this method of data collection to explore the health status of retired professional players in any team based sports. For the current study direct access to the retiree was not permitted. Given this limitation it is difficult to accurately determine the exact response rate. As respondents were contacted by the respective Players’ Associations/Unions on behalf to the candidate,
determination of how many e-mails were valid or if the invitation was actually received, was not possible. These factors may provide a potential explanation for the low response rate observed in the current study.

For the current sample of retired players, the forwards (109.3 kg and 189.1 cm) were heavier and taller than the backs (91.7 kg and 181.5 cm). These findings are consistent with previously published injury surveillance data examining current professional players in the English Rugby Union where the forwards weighed 108.5 kg while the backs were 89.5kg and the stature of the forwards was 188.1cm and the backs 181.3 cm (20). However, this study reported that the forwards were significantly older than the backs (20), while there was no difference in the current age or age at retirement for these two groups in the current study.

3.5.2 Self-reported frequency of neck injuries

One of the primary objectives of this study was to provide an initial overview of the recalled frequency of neck injuries in retired rugby players. In the rugby injury surveillance literature the reported incidence of neck injuries ranges from 0.26 to 10.58 injuries/1000 player-hours (30, 46). For the current cohort 79% of respondents reported that they sustained a neck injury during their rugby careers. As access to the number of playing hours for each respondent in the current study was not possible, comparison between the current findings and the injury surveillance data on active players is not feasible. Relative to other injuries the neck ranked 4th in frequency and the majority of these injuries were sustained during game play. Injury surveillance in professional players has reported frequencies of neck injuries in current players. A study examining the Australian national rugby team from 1994-2000 reported that the neck ranked 7th in frequency (111). While a study in the UK reported that neck injuries ranked in the top five with significantly more neck injuries sustained by forwards than backs (20). Similar results have been reported in an examination of spinal injuries in 12 English Premiership clubs over two seasons where the incidence among forwards was twice that recorded for backs (30).

When the current cohort was split based on playing position, forwards sustained significantly more neck injuries during their careers than backs. When compared to the tackle the fact that scrum involves a higher inherent risk for sustaining a neck injury (30, 100), the difference in neck injury frequency between the two positional groups was not unexpected. However, despite this discrepancy in neck injury frequency in the current study no differences in the
total NDI score or NP and/or NS were observed for the forwards and backs. This potentially implicates general participation in rugby and events during the match (tackles, rucks, and/or collisions) that are consistent to both forwards and backs to the onset of NP and/or NS.

There are a limited number of studies that have examined the long-term health consequences of surgical interventions performed during an athlete’s career; however, the majority of these studies have focused on the lower limb (101-103, 113, 271). For example, Drawer et al. (102) reported a subsequent diagnosis of osteoarthritis in 51% of respondents who had retired due to football related injury to the lower limb. In contrast only 25% of those whose retirement decision had not been influenced by injury reported a diagnosis of osteoarthritis, indicating that the risk of osteoarthritis was increased for those respondents who had sustained a career ending injury. Research examining 20-40 year old female football players twelve years after anterior cruciate ligament injury has reported similar findings (271). Slightly more the 50% of this sample had radiographic confirmed diagnosis of osteoarthritis in their knee and approximately 80% had radiographic features related to osteoarthritis. In the current study participants were asked in an open-ended question to describe ‘a career injury that stood out in their minds’. The neck was the most frequently cited body region with 23% describing injuries that related to this region. Analysis of the major themes in the respondent’s answers revealed that long-term health impact and career ending injury were the most frequently cited themes relating to the occurrence of a neck injury. Thus suggesting that these injuries to the cervical spine have significantly impacted the respondent’s quality of life and continue to do so, with a number of respondent reporting ongoing issues relating to their necks’.

### 3.5.3 Frequency of surgical interventions for the neck

In addition to the frequency of injuries this thesis also examined the number of injuries that required surgical intervention. In the current cohort of 195 individuals a total of 768 surgeries were sustained during the careers’ of the respondents. This translates to an average of 3.9 surgeries per player. The knee was the most frequently cited anatomical area that required surgical intervention and in the injury surveillance literature it consistently ranks in the top three most frequently injured areas (20, 84, 111).

For the current cohort of 195 retired players 9.2% of players sustained a neck injury that required surgery. It was established that most of these injuries occurred during games, which is consistent with the current injury surveillance data for rugby (20, 30, 36). Comparison of
the current findings to survey research examining retired athletes from other sports is difficult, as the majority of research has focused on the lower limb or the incidence of concussion and the long-term impact of these injuries. Rather in the present study comparison is limited to studies that have examined the injury frequency and severity in rugby players who are actively participating in the sport. One such study by Brooks et al. (20) examined the frequency of spinal injuries in 12 English professional rugby clubs over two seasons and reported that no injuries to the cervical region occurred that required surgical intervention. Although, one cervical injury sustained during this time period did result in a player retiring from the sport.

3.5.4 Long-term impact of neck injuries

The majority of neck injuries in rugby are sustained during the tackle (30), which in some cases likely involves similar head-neck segment kinematics as a front or rear-end vehicle collisions. Therefore the examination of the evidence relating to the long-term impact of whiplash may have some applicability to the current population. The development of chronic NP and disability following a whiplash injury sustained in motor vehicle accidents is not uncommon and has been linked to substantial social and economic burdens (239, 249). Investigation into the prognostic capabilities of various factors relating to the whiplash injury event has reported that physical and psychological factors can predict future NP and disability for an individual. Using statistical modelling, the authors’ demonstrated that cold hyperalgesia, loss of cervical ROM, impaired sympathetic vasoconstriction, post-traumatic stress, high pain and disability levels, and older age were strong predictors of poor outcomes six months post-injury (249). Although examination of a number of these predictive variables is outside the scope of a retrospective survey, work with active playing rugby players has documented decreased cervical ROM (44, 48) and impaired CJPS (44, 51). While the current study has observed elevated levels of NP and disability related to this pain. These findings would suggest that retired rugby players may be prime candidates for future NP and disability.

In addition to these findings, a survey examining factors and mechanisms correlated to the occurrence of NP and disability in helicopter aircrew reported that a previous history of neck and shoulder injury predicted those who were currently experiencing NP (272). In the current thesis, surgeries to the shoulder ranked second in frequency (n= 99). While the results regarding injury frequency revealed that the right shoulder ranked 2nd the left shoulder 3rd
followed by the neck which ranked 4th. Given the frequency of neck and shoulder injuries in the current population and the documented presence of neuromuscular impairments in active rugby players (44, 48, 51) the likelihood that players will experience NP after retirement is high, which is supported by the current findings.

3.5.5 Role of the neck musculature and the onset of neck pain

A long-term follow up of 65 whiplash victims 2-3 years after the accident revealed that 55% continued to report NP symptoms of varying degrees (249). In the current population, 5.2 years after retirement, 91% of those that sustained a neck injury during their careers were currently experiencing some form of NP and/or NS. Previous work has examined physical and psychological factors that could potentially predict those likely to experience NP long-term after sustaining an injury. The authors reported that regardless of symptom severity, altered neuromuscular recruitment patterns of the cervical musculature persisted 2-3 years after injury (249). These findings appear to be consistent with other musculoskeletal pain syndromes, particularly those observed for the lumbar spine, where aberrant neuromuscular recruitment patterns persist despite the absence of symptoms (273). It has been proposed that these altered motor patterns may play a role in the high rate of reoccurrence associated with NP (249, 273). This was explored by Sterling et al. (249) who examined the reoccurrence of NP episodes in patients who had sustained a whiplash injury 2-3 years previously. At the time of assessment 40% (n = 26) reported that they were not currently experiencing NP. However, in the 26 recovered participants, 42% (n = 11) still reported intermittent NP that they did not experience prior to the motor vehicle accident (249).

For the current cohort of retired rugby players only 53% of those who sustained a neck injury during their careers were prescribed neck specific exercises by a medical professional. Once the symptoms of the injury resolved only 46% continued to complete the neck specific exercises, while 39% did not and 15% indicated that their symptoms never resolved. Although, reoccurrence was not examined in the current study, injury surveillance data with current players indicates that once a player has sustained a neck injury the risk of reoccurrence is significantly higher (30, 36). This observed reoccurrence rate in professional rugby players may be partly explained by the existence of altered neuromuscular patterns in the cervical spine.
3.5.6 Current pain and stiffness

The neck was the most commonly cited area of current pain for the retired players. The variable current stiffness also yielded similar results, with the neck ranking 2nd in reported incidence after the lumbar region. The majority of respondents attributed this pain (34.6%) and stiffness (30.5%) to ‘training and playing rugby’. A potential explanation for this high frequency of NP and NS in this population is the documented structural changes to the osteoligamentous system (47, 83) and impairments to the neuromuscular systems (44, 48, 51). Despite the limited epidemiological evidence, medical professionals and researchers propose a strong biological basis for linking the occurrence of injury to the early onset of osteoarthritis in load bearing joints (243). Research examining retired professional football players (101, 102, 268) and NFL players (103) supports this hypothesis for injuries sustained to the lower limb, particularly the knee. If this same logic is applied to the neck, one would expect a high prevalence of osteoarthritis in this region, which is supported by the degenerative changes observed in current players’ cervical spines (47, 83). These findings highlight the need of a neck specific intervention to address these neuromuscular impairments and potentially mitigate the reoccurrence of NP and the presence of structural changes to the osteoligamentous system.

In the acute stage following neck injury, NP and headaches are the most frequently cited symptoms and are often attributed to soft-tissue injuries in the area (239, 274-276). However, in the literature surrounding neck injuries following a motor vehicle accident, long-term NP and disability are often referred to as ‘late whiplash syndrome’ and which is controversial and poorly understood (239, 277, 278). In a study examining the frequency of NP in patients that have been admitted to hospital for whiplash injury following a motor vehicle accident 55% of the males, 17 years later reported experiencing NP (239). In the current cohort 80% of respondents reported experiencing some form of current NP and/or NS 5.2 years after retiring from rugby. This percentage is substantially higher than the reported NP prevalence in the general population, 7.6% for adults 15-74 years of age (45). These findings are consistent with research conducted in Sweden examining the current health status of individuals who had sustained a whiplash injury during a motor vehicle accident. Compared to the general population these individuals were at significantly higher risk of experiencing neck and shoulder pain, 7 and 18 years after injury (239, 279), which is consistent with the evidence presented in the current study.
A more concerning statistic is that 27.4% of respondents from the current cohort were constantly experiencing some level of NP and/or NS. These findings highlight the prevalence of this disorder in the population. For those reporting constant NP and/or NS the likelihood that their symptoms have some form of impact on their quality of life or overall health is high. Individuals reported that the most symptomatic activities were ‘sleeping and getting up in the morning’, ‘sitting’ and ‘driving’. However, previous work with retired NFL players has proposed that these individuals may be better adapted to dealing with limitations imposed by physical impairments due to their past experience playing and training through injury and pain (103). Therefore the impairments imposed by NP and/or NS could potentially be less significant for this cohort of retired athletes than it would be in the general population. Another possibility is that there is an under reporting of NP and/or NS in this cohort as they have grown accustomed to experiencing some level of pain and/or stiffness in this region and are repressing these symptoms.

3.5.7 The Neck Disability Index

The NDI was developed to evaluate the level of disability in patients suffering from NP (236). Despite forwards sustaining significantly more neck injuries than backs (30, 36), there was no difference in total score for the NDI between the two groups. Breaking the total score into the individual items, forwards reported significantly higher levels of ‘pain intensity’ (1.17) than backs (0.83). This finding is consistent with previous research that examined individuals (n= 121) who sustained a whiplash injury during a vehicle accident 17 yrs previously and compared them to healthy controls (n= 1491). Those who had previously sustained the whiplash injury scored significantly higher on the ‘pain intensity’ item than the control population (239). Given the higher frequency of neck injuries for forwards in the current injury surveillance literature (20, 27, 30, 36) our findings for ‘pain intensity’ are consistent with these results. However, the total score for the group exposed to the whiplash injury event was significantly higher than the control population, indicating that 17 years after the event the injury still had a substantial impact on the functioning of the affected individual (239). The lack of difference in the overall NDI score for the retired forwards and backs could also indicate exposure to a mechanism that is common for both forwards and backs. This speculation is supported by the presence of degenerative changes in the osteoligamentous and impaired cervical ROM and CJPS in both forwards and backs (44, 47,
Although, not statistically significant, the individual component scores for both ‘lifting’ and ‘driving’ just failed to reach statistical significance for the forwards and backs.

Comparison of the total NDI scores for both the forwards (7.41 ± 7.46) and the backs (6.34 ± 7.43) revealed that they were slightly higher than the scores recorded for a control population (5.3 ± 7.6) with a mean age of 55 (36-83 yrs) that included both males and females (n= 931) (239). The NDI findings for the current study are also higher than the total scores observed in a Japanese study (3.61 ± 4.88) of healthy males between the ages of 30-39 (n= 100), which encompasses the mean reported age (37.79 yrs) of the current survey respondents (240). The scores reported in the present study for both forwards and backs were approximately double this value, indicating that the NP experienced by the rugby cohort had a larger impact on self-reported disability than that observed for a cohort of age-matched males from the general population. The study by Kato et al. (240) also reported that those individuals with upper limb symptoms scored higher on the NDI. Given the frequency of upper limb injuries in the current cohort it is likely that some respondents were currently experiencing pain in this region, which may have also impacted on the NDI scores.

3.5.8 Limitations

This survey was a retrospective epidemiological investigation into injuries sustained during a player’s career and their current health status. The method of data collection was dependent on the respondents’ memory recall and thus involved the inherent risk of ‘retrospective contamination’ (280). An epidemiological examination of injury compared prospective injury surveillance data to retrospective injury recall and reported that higher injury rates were recorded prospectively. The authors proposed that when recalling injuries retrospectively minor injuries were not readily recalled, thereby resulting in lower recorded injury rates. However, there was no difference between the two methods of data collection when distribution of injury by anatomical location and type was observed (276, 280). As the focus of the current survey was on the distribution of injury by anatomical location and the relative frequency of these injuries with the exception of surgical intervention, the risk of ‘retrospective contamination’ appears to be minimal. The descriptive nature of the survey data on which our findings are based prevents the formation of firm conclusions on the causal nature of injuries to this region or the progression of pathological changes. A further limitation of this study is the possibility of self-selection bias, as retired rugby players with current health concerns and/or a history of medical treatment since their retirement may have
been more likely to respond because of the salience of the topic. This may have implications for true proportion of retirees currently experiencing health related concerns relating to their past rugby experience (268).

3.6 Conclusion

The purpose of this study was to investigate and retrospectively describe the frequency of neck injuries sustained by retired professional rugby players during their careers, and explore the long-term impact of these injuries and rugby participation. In this cohort of retired professional rugby players neck injuries were a frequently reported event during their career. Over the span of their rugby career 79% of respondents indicated that they had sustained a neck injury. Of these, 91% reported that they were currently experiencing some form of NP and/or NS. Relative to other regions of the body the neck was the most commonly cited area of pain and the 2\textsuperscript{nd} most frequent area of stiffness. These findings highlight the frequency of neck injuries and the potential for development of long-term NP and NS once players have retired. These findings provide sufficient evidence to indicate that neck injuries sustained during the careers of rugby players will have long-term consequences that for some may impact on their quality of life and, thus, warrant further investigation.
Chapter 4

Experimental Protocol and Design of the Fixed Frame Dynamometer to Assess Neck Strength and Endurance in a Simulated Contact Posture
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4.1 Introduction

Training to improve strength, fitness, skill acquisition is an accepted practice in both professional and amateur sport (129). In this sporting context, training programs targeting the lower or upper limb have been shown to reduce the incidence of injuries to both the knee and the shoulder (129, 218-220, 227, 281). A similar theoretical injury reduction rationale has not been examined in the context of minor non-catastrophic neck injuries (55). In order to determine whether cervical strength and endurance may play a role in reducing the frequency of minor neck injuries, it is necessary to reliably quantify and evaluate these parameters (59). Quantification of cervical strength in rugby union players has been neglected with only one individual case study (88) and a few single observational studies published to date (74-76).

As previously described (Chapter 2), minor injuries to the cervical spine are common events that occur most frequently during match play (30, 36, 87). Neck pain (NP) is one of the primary symptoms of minor neck injuries (64). Examination of this symptom in amateur players has reported a high prevalence level, particularly for those that play in the forwards (83%) (44). However, data regarding the prevalence of NP and minor neck injuries in collision athletes are limited, presumably because injury surveillance efforts have focused on catastrophic injuries to the neck (24, 55). Work with other populations using various tools to evaluate performance has demonstrated that individuals with NP have: (a) greater fatigability of the superficial prime movers, (b) impaired neuromuscular efficiency of the superficial prime movers, (c) impaired recruitment of the deep cervical flexors compensated for by increased superficial muscle activity, and (d) impaired peak force production in the cervical musculature (5, 61, 67-70, 123, 125).

Neck strength and endurance have been highlighted as valuable parameters for the clinical assessment of individuals with NP and/or injury, and for the documentation of progress in response to the implementation of a neck specific intervention (58, 59). Due to the technological issues surrounding the anatomical and mechanical axis of rotation when evaluating the neck isokinetically, the decision was made to design a device that would facilitate the isometric assessment of neck strength and endurance (59).

Neck muscle strength primarily has been investigated in a seated position with the neck in a neutral vertical posture (58, 74, 165). Although this posture has been found to provide a reliable measure of isometric neck strength, its practical relevance to collision sports where the neck is loaded in a primarily horizontal body position may be limited. In addition, due to
the documented evidence for the presence of degenerative changes in the cervical region of rugby players, all testing was conducted in a neutral neck posture, to minimize the potential for injury during testing (47, 83, 98).

Most neck strength research has been completed in either the seated or supine positions (6, 76, 88). In the seated position, isolation of the cervical musculatures has been achieved by securing the trunk with a four point safety harness (6, 76), and techniques have been utilized to limit force contribution from the legs (95, 163). While these apparatuses and protocols have provided valid and reliable measures of cervical strength, their findings provide questionable relevance to collision sports such as rugby, where the majority of neck injuries occur during contact events when players are running or tackling in the horizontal plane (30, 36, 87). Given this horizontal position of loading, one of the principle objectives in the design of the apparatus was to simulate a posture that would be functionally relevant for rugby. Therefore, the device was designed to simulate the body posture adopted during contact with the trunk in a horizontal position. In order to obtain an ecologically valid assessment of neck strength and endurance, the decision was made to refrain from restraining the trunk or hips during testing, rather chest and forearm benches were used to help standardize the body position between repeated testing sessions. No other attempts were made to limit contributions to peak force or endurance production from synergistic muscles of other body regions. In order to simulate the wrapping of the arms around an opponent’s body in the tackle situation, hand grips were provided.

As this device was to be used in field-based settings, it was important that testing be completed in a timely and efficient manner. These necessary requirements precluded the use of EMG; therefore a time dependent method of endurance assessment was selected. Portability was also an important factor to consider when designing the device as it was to be used in field-based settings; however, measurement validity and reliability were also essential considerations. Although handheld dynamometry is the most portable method of strength and endurance assessment for the neck, the vulnerability of this method’s reliability and validity to examiner bias led to the selection of a fixed frame dynamometry device (58, 59).

As this testing protocol was designed to evaluate rugby players, a relatively high level of strength and endurance was expected. As previously published isometric endurance assessment of the cervical spine have reported using resistance loads of 70% MVC (5, 6, 68, 209), a similar protocol was followed. Examination of between-day reliability in helicopter
pilots had reported that endurance trial length should exceed 45s (209). The 70% resistance load for extension (Ext), flexion (Flx), left (LtFlx) and right lateral flexion (RtFlx) all exceeded a mean value of 45 s for both examined studies (5, 6).

The purpose of this chapter is to describe a novel testing apparatus that facilitates the evaluation of neck strength and endurance isometrically in a neutral neck posture with a body position functionally relevant for collision sports such as rugby. Part 1 of the chapter describes the testing apparatus, and a study conducted to assess the peak force reliability of the apparatus and experimental protocol in Ext, Flx, LtFlx and RtFlx. Part 2 describes the test-retest reliability of Ext and Flx peak force and endurance measures over three separate testing sessions.
Part I

The intra-session reliability of repeat isometric neck strength testing in a simulated contact posture
4.2 Part I: Introduction

A relationship between improved strength and reduced injury incidence in collision sports has been widely postulated but rarely substantiated. Good muscular strength is assumed to provide better joint stability, movement control, resistance to fatigue and ultimately greater functional protection. In rugby, the reported incidence of neck injuries ranges from 0.26 to 10.58 injuries/1000 player-hours (30, 46). These cervical injuries range from minor impairments to severe catastrophic injuries with the latter having been more extensively researched (88, 97, 98). Despite the substantial human and medical burden of catastrophic cervical injuries, these are fortunately relatively infrequent in sport (97). Severe neck injuries (> 3 weeks missed play) during game play accounted for 6.7% of the total injuries sustained by 262 male amateur rugby players while minor injuries (< 1 week missed play) accounted for 68.0% (36).

Examination of the symptoms of minor neck injuries has highlighted NP as one of the primary symptoms (2). In amateur rugby players, a NP prevalence of 83% in forwards and 41% in backs has been reported (44). In comparison to the 10-20% of the general population reporting NP, this incidence is substantially higher (134). In collision sports like rugby, physical loading of the cervical spine is unavoidable. For rugby, these loading factors have been proposed as the prime contributors to the documented impairments in cervical ROM (44, 48) and CJPS (44, 51), and the pathological changes to the vertebrae and discs in the neck (47, 83, 98). The role cervical musculature may play in absorbing and alleviating some of these external forces remains unknown. The stability of the cervical spine is derived from “the inherent passive stability of the spinal column and the highly developed active stability provided by the surrounding muscles” (115). Cervical muscles contribute approximately 80% to the total stabilization of the neck (115). Any factor that compromises the force generation capacity of these muscles could potentially place the individual at an increased risk of a neck injury or NP.

Isolating the cervical musculature for conditioning or testing is problematic (58). Technological issues arise when evaluating the neck using dynamic methods of assessment due to the difficulty in determining the neck’s axis of rotation. Thus, the majority of neck strength assessment is conducted using isometric protocols (58, 59). Isometric cervical strength assessment mirrors the physiological demands placed on these muscles during daily activities (39, 168). These muscles are required to maintain static low level isometric
contractions to support the head during activities such as sitting and standing (39, 58). The two most commonly used methods of isometric cervical strength quantification are: (a) handheld dynamometry, and (b) fixed frame dynamometry (58, 59). Handheld dynamometry uses a device with a load cell interfaced between the examiner and participant. While the participant performs an isometric contraction, the examiner provides resistive force and proximal stabilization for contractions that are either participant initiated or examiner initiated (169, 170). Although this form of assessment allows the examiner to quantitatively assess cervical peak force, its reliability and validity are vulnerable to the strength of the examiner, position of the examiner, neck position and the ability of the examiner to stabilize the participant (169). Fixed frame dynamometry, the most common method of cervical strength evaluation in research, is considered the gold standard for isometric strength quantification (58, 59). Unlike handheld dynamometry, the examiner is not required to provide stabilization or resist movement. In fixed frame dynamometry, the load cell is attached to a fixed base, either wall or frame mounted, that adjusts to accommodate individuals of different size (58, 59).

The amplitude of neck movements are small and therefore providing resistance in a safe and effective manner is challenging, particularly given the degenerative changes observed in the osteoligamentous system of rugby players (47, 83, 98). Despite these practical constraints, studies using different fixed frame dynamometers have examined neck muscle strength in female office workers (40), whiplash patients (282), individuals with chronic NP (94), fighter and helicopter pilots (65, 78), race car drivers (176) and healthy controls (93). In general, a relationship between strength deficits and the presence of NP has been demonstrated (65, 78). However, a number of contrary findings have also been reported (78), highlighting the complexity of NP and the issues surrounding assessment and quantification of the physiological characteristics of the neck musculature.

Most neck strength research has been conducted in either a seated or supine position (6, 76, 88) with a limited number of studies conducted in a standing position (165). Given the variety of testing postures, comparisons of the literature regarding reliability and validity are confounded. This statement is clearly supported by the disparity in reported peak strength for the cervical extensors which ranges from 22-245 N. To examine the impact testing position has on the magnitude of neck strength a study compared peak force in a seated and standing posture (165). The maximum strength values achieved in standing were significantly lower than those achieve in a seated position, with the exception of left and right rotation. The
authors attributed these findings to compensation from other parts of the body, specifically the trunks and legs, to peak force values. This interpretation is further supported by the ICC coefficients reported for the different testing position, which indicate that when the body is able to augment force production at the neck from other regions, ICC values are decreased (seated: ICC 0.84-0.90). When better isolation of the neck muscles is achieved, ICC values are increased (standing: ICC 0.89-0.96) (165). Better isolation of the cervical musculature in a seated position has been achieved by securing the trunk with a four point safety harness, (6, 76) and utilization of different techniques to limit force contribution from the legs (95, 163). When these techniques have been employed, ICC coefficients for the same measured directions have improved to 0.89-0.95 (167). While these apparatuses and protocols have provided valid and reliable measures of cervical strength, isolation of the cervical musculature in this manner raises questions with regard to the functional relevance of the actual measures. This uncertainty is particularly true for collision sports such as rugby, where the majority of neck injuries occur during contact events where players are rucking, scrummaging or tackling with forces applied in the horizontal plane. Quantification of cervical strength in rugby players has been neglected with a limited number of studies published (73-76, 88). To better evaluate the role that neck musculature conditioning may play in the occurrence of neck injury and NP in rugby, better quantification and long-term monitoring of force production from these muscles by the medical, strength and conditioning and coaching staff is essential.

### 4.3 Part I: Research Questions

The purpose of this study was to: (1) to develop a functional and reliable testing apparatus and experimental protocol that would permit evaluation of neck musculature maximal force production in a simulated body contact position; (2) to establish the within day reliability of repeated measurement with this device. This testing posture was based on the body position adopted during contact events such as tackling, scrummaging, rucking, and/or mauling, and the propensity for these events to result in injury to the cervical spine. Peak force production of the cervical spine was examined in Ext, Flx, LtFlx, and RtFlx directions over three repeated trials during a single testing session. Reliability of this custom designed testing apparatus was assessed through the use of relative and absolute reliability parameters.
4.4 Part I: Methods

4.4.1 Ethics

Institutional ethical approval was obtained from the University of Otago Human Ethics Committee (Appendix D) and the Ngāi Tahu Research Consultation Committee (Appendix E).

4.4.2 Participants

Physically active, male participants were recruited from a student population and informed consent was obtained (Appendix F). Participants were excluded if they engaged in collision sports or had received treatment in the previous three months for any of the following: a) musculoskeletal injury to the cervico-thoracic spine; b) cervicobrachialgia or shoulder pain during neck movement; c) radiating pain when overloading the cervical spine (40).

4.4.3 Testing apparatus

Based on the design criteria identified from the review of literature an initial design of the testing apparatus was proposed (Version 1). Table 4.1 provides a completed summary of the key factors in the design of the device. Version 1 of the device was then discussed with a panel of scientists and experts in the field including physiotherapists, a scrum coach, and strength and conditioning coaches involved with rugby at the professional level (expert group). Key discussions focused around the body position used for strength assessment (Version 2). The primary design criterion for the testing apparatus was to simulate the posture adopted when scrumming or when making a tackle or entering a ruck. Current best practice guidelines suggest when making a tackle the ‘face is up and shoulders should be above hips’ or when going into a scrum ‘shoulders are above hips and head is up and chin is off the chest’ (139, 283). Despite these best practice guidelines, it was considered ethically unacceptable to ask players to perform MVC in non-neutral neck position given the potential for injury in this position. In addition, difficulties arose regarding design of an apparatus that permitted a body position with the shoulder above the hips where the neck could still be tested isometrically in a neutral position and the body position be standardized. Based on these design constraints, a horizontal body position was selected. Further work is warranted to harmonize the development of a testing apparatus in keeping with best practice tackling advice. Based on input from the expert group and the design engineer who consulted on the development of the
testing apparatus, a neutral neck position and horizontal body posture was chosen. A summary of the design processes for the testing apparatus is illustrated in Figure 4.1. As the simulated testing position was acknowledged to approximate a body position adopted during game play by the experts, the candidate chose to use the term simulated body contact position to describe the posture adopted in the testing apparatus. The testing apparatus included: (1) an adjustable padded chest bench; (2) adjustable forearm bench; (3) a vertical pole mount with a headpiece (Figure 4.2).
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<th>Design criteria</th>
<th>Justification</th>
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<tr>
<td>Method of quantification</td>
<td>Isometric</td>
<td>- Mimics postural function or neck muscles</td>
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<td>- Do not have to consider axes of rotation</td>
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<td></td>
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<td>- Easy to perform</td>
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<td>Device</td>
<td>Fixed frame dynamometry</td>
<td>- Time and cost effective</td>
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<td>- Good to excellent reliability</td>
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<td>- Portable</td>
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<td>Neck position during testing</td>
<td>Neutral</td>
<td>- Horizontal neck position functionally relevant for contact sports</td>
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<td>- Reduce risk of injury during testing</td>
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<td>- Generally position where highest peak force values obtained</td>
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<td>Body position</td>
<td>Simulated tackle stance with chest supported</td>
<td>- Ecological validity</td>
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<td>- Reduce compensation from synergistic muscles and other body segments</td>
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<td>- Standardization between repeat testing sessions</td>
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<td>Warm-up</td>
<td>5 min neck and shoulder warm-up will be performed before any strength or endurance testing</td>
<td>- Improves temperature related mechanisms</td>
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<td>- Enhanced participant acclimation</td>
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<td>Time of assessment</td>
<td>Limited influence on time of assessment due to training times and participant availability.</td>
<td>- Limit confounding variables</td>
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<td>- Aim for evenings and approximately the same time of day (within 30 mins)</td>
<td>- Peak force obtained between</td>
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<td>Endurance trial</td>
<td>Static time-dependent method: times to fatigue and area under force curve</td>
<td>- Time constraint during testing</td>
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<td>Resistance load for endurance test</td>
<td>70% MVC</td>
<td>- Previous research has been conducted using this resistance load</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Previous research has indicated trial length for Flx, Ext, LtFlx and RtFlx all exceeded 45s which has been reported to enhance inter-trial reliability</td>
</tr>
</tbody>
</table>
Figure 4.1: Summary of the design process for the development of the testing apparatus

- **Version 1**: Identification of key design components from review of literature
- **Version 2**: Discussion with expert group and design engineer, Identification of conflicts arising between best practice body position recommended for contact and safety constraints for testing
- **Version 3**: Testing apparatus designed with neck in a neutral posture with body in a horizontal position (simulated contact position)

Figure 4.2: Simulated tackle isometric neck strength assessment device

The headpiece consisted of padded adjustable mounts that were aligned to the anterior, posterior, left, and right sides of the participant’s head. Each mount included a PTASP6-D 40 kg single point load cell (Precision Transducers, Auckland, New Zealand) that was attached to a high density foam pad. Load cell signals were amplified (MF60, Micron Meters, Simi
Valley, CA), and recorded via custom software designed to record maximal force production in Ext, Flx, LtFlx and RtFlx. The manufacturer’s load cell calibrations were verified before and after the completion of the study using known weights between 2.64 – 24.95 kg.

### 4.4.4 Experimental procedure

Prior to any strength measurements, each participant’s body mass (kg), stature (cm) and neck circumference (cm) were measured (Appendix G). Neck circumference was measured just below the larynx in the horizontal plane using an anthropometric tape and recorded to the nearest 0.2 mm (93). Participants were instructed to look straight ahead and the average of two circumference measurements was recorded.

Prior to any strength measurements, participants were asked to rate their current levels of NP and NS, and average and worst levels over the previous three weeks using a VAS (6, 284). The VAS were 100 mm straight lines anchored with labels ‘no pain/stiffness at all’ (0 mm) and ‘worst possible pain/stiffness imaginable’ (100 mm) (6, 40, 284). NP was defined as an unpleasant sensory and emotional experience associated with actual or potential tissue damage (1) relating specifically to the neck. NS was explained as the resistance that the neck offers during movements or when starting a movement such as turning the head (3). Participants were told that NS can include muscle stiffness which is defined as a feeling of tightness or resistance to stretch in the muscle in the absence of pain. It was explained that NS can change throughout the day, for example it may be worse in the morning or may improve or worsen during exercise (3).

For each testing session, participants completed a standardized 5-min warm-up for their neck and upper back muscles (Appendix H). The warm-up consisted of 3 sets of 10 reps of each of the following exercises: shoulder shrugs, shoulder circumductions, shoulder protraction and retraction and neck half circles performed in each direction (6). Participants were then asked to assume a simulated contact position on the testing apparatus. In this stance, the participant’s neck was positioned in a neutral posture. This neck posture is the most frequently cited testing position (5, 40, 71, 88, 172, 285) and is assumed to present the lowest level of injury risk during testing (58). Biomechanical modelling has also indicated that the neck musculature is capable of maximal force production in this position (175). The mounts of the headpiece were aligned inferiorly above the eyebrows, superiorly above the occipital protuberances, and above the top of the ears (Figure 4.3). These placements have been recommended for testing in a seated position (58). The participant’s chest was positioned on
a padded bench adjusted to a height that would provide a 90° angle at the hips. They were instructed to place their forearms on an additional pad which contained hand grips to guide the hands to simulate a tackle position and minimize trunk movement during testing. This bench was adjusted to provide 90° of elbow flexion. Following this positioning, the resting weight of their head on the four force transducers was recorded. These values were subtracted from the maximal values achieved during each MVC to account for resting pressure on the force transducers.

Figure 4.3: Position of force transducers around the head

Immediately preceding data collection, participants were familiarised with the apparatus and tasks by performing two to three submaximal contractions and then a single unrecorded MVC in each direction. To avoid any rapid jerking movements that could result in neck injury or measurement artefacts, participants were instructed to gradually ‘ramp up’ to maximal force production (approximately three seconds) (6). Verbal encouragement was provided during each MVC (6, 59). Three isometric MVCs were performed for each direction: Ext, Flx, LtFlx and RtFlx in a randomly determined order. To avoid bracing against the bench, participants were instructed to lift their forearms slightly off the forearm bench during each trial. For each MVC, the contraction was held for a period of 5 seconds (s) with a minute rest between trials. The maximum force achieved during the 5 s was recorded as the MVC. Peak force was recorded in Newtons (N).
4.4.5 Statistical analysis

Descriptive statistics (mean and SD) were calculated for each of the three trials in each of the four directions. A 4(directions) x 3(trials) repeated measures ANOVA was used to examine the main effects for trials and direction and for a possible interaction. A one-way ANOVA was used to explore differences between the three trials for each direction. A Greenhouse Geisser correction factor was applied for any violations of sphericity and Bonferroni pair-wise comparisons were used to explore differences between trials and directions.

To determine the relative reliability of the device, average and single measure Intra-class Correlation Coefficients (ICC\(_{3,1}\)) and 95% confidence intervals (95% CI) were calculated using MVC values from the 3 trials for each of the four directions. The ICCs were evaluated using the following criteria: poor ICC<0.50, moderate 0.50<ICC< 0.70, good 0.70<ICC<0.90, and excellent ICC>0.90 (163).

Absolute reliability was determined using the measurement error associated with a single MVC measurement, calculated as the standard error of measure (SEM) using the following formula: SEM = SD x \(\sqrt{(1-\text{ICC})}\) (286). The SD of the three trials combined was used and the ICC used was the 2-way mixed model single measure consistency value. This ICC value was chosen as it reflects the error associated with a measurement collected at a single point in time (163). The error associated with multiple measures of maximum strength for each of the four directions was calculated as the minimal detectable change (MDC). The MDC is the smallest amount of change in the MVC scores that can be considered actual change that exceeds error in the measurement. This value was determined using the formula: MDC = 1.96 x \(\sqrt{2}\) x SEM and was calculated to the 95% confidence level (287). A Pearson correlation analysis was conducted to examine any relationship between NP, NS, and MVC values. SPSS 19.0 (IBM SPSS Statistics, Somers, N.Y.) was used for all statistical analyses and the criteria for statistical significance was set at \(\alpha=0.05\).

4.5 Part I: Results

The mean age, weight, height and neck girth of the 14 male participants were 27.14±8.26 years, 79.98±11.8 kg, 179.91±6.74 cm, and 38.58±2.01 cm, respectively. Descriptive statistics for the isometric peak force values for the three trials for each direction are presented in Table 4.2. The main effect for trials was \(F_{(2,26)}= 5.59, p= 0.03\). Bonferroni post-hoc pair-wise comparisons indicated that trial 1 was less than trial 2 \((p< 0.001)\); however,
there were no differences between trial 1 and 3 or 2 and 3. The main effect for direction was $F_{(3,39)} = 49.96, p < 0.001$. Post-hoc tests established that Ext was stronger than the other three directions: Flx ($p < 0.001$), LtFlx ($p < 0.001$), and RtFlx ($p < 0.001$). No differences were isolated between Flx, LftFlx and RtFlx. The interaction effect for trial x direction was not statistically significant, $F_{(6,78)} = 0.13, p = 0.99$, indicating that any change over the three trials was consistent across the four directions.

Due to the statistically significant main effect for trials, a repeated measures ANOVA was conducted for each direction. The results for the three trials for Ext, Flx, LtFlx and RtFlx directions all produced statistically non-significant findings, $F_{(2,26)} = 2.34, p = 0.12$; $F_{(2,26)} = 1.01, p = 0.34$; $F_{(2,26)} = 2.56, p = 0.12$; and $F_{(2,26)} = 2.53, p = 0.10$, respectively. Observed power computed for these results was found to be low (Ext 0.41, Flx 0.16, LtFlx 0.35 and RtFlx 0.44), in contrast to that of the main effect for trial in the repeated measures ANOVA (0.65). This lower value was because the trial means from the ANOVA were averaged over direction, resulting in lower variance and higher power than was the case for the data from each direction.

Mean NP VAS scores were as follows: ‘current’ 2.32±4.56 mm, ‘average’ 5.36±8.53 mm, and ‘worst’ 14.07±20.12 mm over the last three weeks. NS values were ‘current’ 10.43±11.08 mm, ‘average’ 12.57±12.94 mm and ‘worst’ 21.61±19.88 mm. No statistically significant correlations were found between NP and NS and mean MVC values for the four tested directions.

The single measure ICC\(_{(3,1)}\) for Ext, RtFlx, and LtFlx were all excellent and ranged in value from 0.91 to 0.94, while the Flx direction was considered good with a value of 0.86. The average ICC\(_{(3,1)}\) scores over the three trials were all excellent (0.91-0.97). Absolute and relative reliability values are reported in Table 4.2. The highest SEM was achieved for Flx (19.04 N), while RtFlx was the lowest (13.80 N). When the MDC was compared to the overall mean for each direction, changes greater than 18.53% for Ext, 37.44% for Flx, 33.17% LtFlx and 31.08% for RtFlx would be required to indicate that a statistically significant change had occurred in neck strength.
Table 4.2: Maximal isometric neck strength (N) and reliability in a simulated rugby contact position in males (n= 14)

<table>
<thead>
<tr>
<th>Direction</th>
<th>Trial 1</th>
<th>Mean</th>
<th>SD</th>
<th>Trial 2</th>
<th>Mean</th>
<th>SD</th>
<th>Trial 3</th>
<th>Mean</th>
<th>SD</th>
<th>Overall Mean</th>
<th>Mean</th>
<th>SD</th>
<th>ICC(3,1)</th>
<th>95% CI</th>
<th>SEM</th>
<th>MDC</th>
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<tbody>
<tr>
<td>Extension</td>
<td>227.61</td>
<td>60.90</td>
<td></td>
<td>236.34</td>
<td>55.51</td>
<td></td>
<td>240.36</td>
<td>49.33</td>
<td></td>
<td>234.77</td>
<td>54.33</td>
<td></td>
<td>0.92</td>
<td>0.97</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion</td>
<td>135.04</td>
<td>36.68</td>
<td></td>
<td>143.18</td>
<td>45.40</td>
<td></td>
<td>144.75</td>
<td>41.58</td>
<td></td>
<td>140.99</td>
<td>40.56</td>
<td></td>
<td>0.86</td>
<td>0.91</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LftFlx</td>
<td>127.58</td>
<td>51.78</td>
<td></td>
<td>134.35</td>
<td>51.88</td>
<td></td>
<td>141.61</td>
<td>63.84</td>
<td></td>
<td>134.53</td>
<td>55.05</td>
<td></td>
<td>0.91</td>
<td>0.97</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RtFlx</td>
<td>116.11</td>
<td>53.25</td>
<td></td>
<td>125.92</td>
<td>59.72</td>
<td></td>
<td>127.00</td>
<td>52.66</td>
<td></td>
<td>123.03</td>
<td>54.17</td>
<td></td>
<td>0.94</td>
<td>0.98</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*All values are reported in Newtons (N)
† 95% Confidence Interval for the ICC(3,1) Average Measure
4.6 Part I: Discussion

The present study was designed to develop and evaluate a strength testing apparatus that would permit, within the constraints of a neutral neck posture, a quantification of functional neck strength. Reliable quantification of cervical strength would enable clinicians and strength and conditioning staff to pre-screen players to identify those at-risk and to evaluate changes in neck strength in response to different events, such as a rugby season and/or an exercise intervention or rehabilitation regimen. In addition, this information could be used by coaches to evaluate players based on positional requirements and as feedback for players on their training progress. The testing apparatus used an ecologically derived novel testing posture with participants positioned in a simulated contact position. This stance was implemented in order to address some of the functional limitations in previous research (2, 48, 95), and to make it relevant to the demands of the game. The reliability of the device was evaluated using three repeated MVC trials over a single session for Ext, Flx and LtFlx and RtFlx. The average relative reliability (ICC) was found to be excellent for all four testing directions, indicating that the apparatus is a reliable tool to assess isometric neck strength. This study also established absolute reliability values (SEM and MDC) in four directions in a sample of healthy males. The reliable nature of the measures makes this a valuable tool to examine changes in peak force over time.

The values obtained in a simulated contact posture agree with previous research conducted in a seated position, in that the largest maximal force was achieved in Ext (95, 167, 175). The current study cohort of young, healthy males produced Ext (234.77 N) results that were substantially higher than previous published results for comparable participants (45.1 -100 N) (167, 175). These findings were not unexpected, given that the testing position in the present study allowed participants to brace their upper extremities with the hand grips allowing greater trunk stabilization which likely augmented cervical musculature force production. Compared to a sample of physically fit men (age 21.6 yrs), the present Ext results are slightly lower than those reported by Almosnino et al. (95) (251.95 N) despite the difference in measurement methods. Similar results were observed for Flx, LtFlx and RtFlx, with our participants recording MVCs higher than those reported for similar samples (167, 175). This difference may be explained by the fact that current cohort consisted of physically active university students. However, these values were below the peak force values achieved by physically fit males (95), indicating agreement between the current study’s novel testing apparatus and other testing systems.
The excellent average-measure relative reliability for each of the tested directions (ICC\(_{(3,1)} = 0.91\) to 0.98) indicates that repeated trials are not needed to measure isometric neck strength. Similar ICC values have been reported for physically active participants for these four directions (95), but our values are slightly higher than those reported for a sample of healthy age-matched individuals (167). The lowest relative reliability and largest absolute reliability was demonstrated for the Flx direction, which is consistent with other research (95). It may be that participants initially had difficulty recruiting their cervical flexors to perform a maximal contraction as the movement is rarely performed during daily activities.

To determine clinical significance, absolute reliability (SEM) was calculated for each direction (Ext 15.69 N; Flx 19.04 N; LtFlx: 16.10 N; RtFlx 13.80 N), which indicates the level of agreement for the peak force values between the repeated trials (163). In the current study’s sample, a change of greater than 43.50 N for Ext, 52.79 N for Flx, 44.62 N for LtFlx and 38.26 N for RtFlx would be required to indicate a clinically significant change had occurred over time or with an intervention.

The majority of isometric neck strength testing research has been conducted in the seated position with the participant’s torso restrained (58, 76, 167). Stabilization of the trunk is considered essential for reliable and valid cervical strength measurements as this stabilization will limit the contribution of other extrinsic muscles to force production (95). The research objective of the present study was to develop a testing apparatus that would yield reliable neck strength measures that were functionally relevant to the physical demands placed on the neck during a game of rugby (ecological validity). Seated testing with torso restraint would have limited the content validity and functional relevance of strength measures. In the current study, the trunk was not restrained. Rather, participants’ trunks were stabilised by using benches to help maintain a horizontal body posture. Contribution of extrinsic muscles to force production therefore was expected. Despite the trunk not being stabilized, the current testing apparatus permitted the production of reliable measures of cervical musculature peak force in a healthy untrained male population.

### 4.7 Part I: Conclusion

Currently there is no examination of neck strength in rugby players over the length of a competitive season. The testing apparatus and experimental protocol detailed in this study provides a reliable measure of maximal force production for Ext, Flx, LtFlx and RtFlx that may have practical applications for rugby and other collision based sports. Relative reliability
measures have been established which will allow for assessment of strength changes over the season or an exercise intervention. Future research should target examination of neck strength, along with self-reported NP and NS over the course of a rugby season. Application of this device for future research would permit the reliable quantification of cervical strength in a simulated contact position, to determine whether there is a relationship between the measures of neck strength and endurance and NP and/or injury.
Part II

The reliability of inter-session isometric neck strength and endurance in a simulated contact posture
4.8 Part II: Introduction

The human cervical spine has evolved to perform three basic functions: to carry large loads, to move the head in multiple directions, and to protect the nerves located within the spinal canal (115). In order to accomplish these functions, the cervical spine must be mechanically stable when performing dynamic and isometric contractions. Cervical spine stabilization is achieved through both ligamentous and muscular involvement, with the former predominantly involved at the end of the range of motion (118), the latter providing dynamic support to movements within neutral and slightly deviated postures (120, 164). A number of authors have proposed that improved neck strength and/or increased neck girth could potentially improve neck stability and prevent or reduce the occurrence of neck injuries in contact sport (51, 76, 88). Currently there is little understood about the relationship between neck strength and neck injury/pain (75, 91). This lack of evidence highlights the need for testing methods that will allow the assessment of neck strength in positions functionally relevant for the demands placed on the neck during sport, the establishment of normative data, and the tracking of changes in neck strength over the course of a season and/or career.

In collision sports such as rugby union, the head and neck are repeatedly exposed to potentially injurious situations over an 80 min game. The majority of neck injuries sustained in the sport are classified as being minor in severity (30, 34, 36) with an average and median severity of 13 and 5 days, respectively of missed training/play (30). In research that examines collision sports, it has been reported that one of the primary symptoms of these injuries is NP (64).

Magnetic resonance imaging (MRI) and x-ray have been used to examine the physical changes to the cervical region as a result of sport participation, revealing cervical disc degeneration, stenosis, and other pathologies that could increase the potential for sustaining additional or more severe neck injury (47, 83, 98). The potential for repeated minor neck injuries to lead to pathological changes in the cervical spine is an area of concern for both medical and rehabilitation professionals (47, 83, 98). The question then becomes: what can be done to prevent these injuries from happening, or how can one reduce the severity of future injuries?

The cervical musculature plays a key role in absorbing and controlling the forces applied to the cervical region during participation in collision sports. These functions would be reflected in the musculature’s ability to develop maximal contractions (peak force) and to sustain
prolonged submaximal forces (endurance) (58). Cervical musculature peak force commonly has been used as an indicator of neck muscle dysfunction (58, 59, 61), with a number of studies on different populations reporting strength decrements in individuals with NP (6, 65, 94). In contrast, other studies on neck specific interventions have documented improvements in force with no subsequent reductions in NP (58, 59, 72).

Fewer studies have evaluated neck muscular endurance in comparison to research examining neck strength (58, 163). The few studies that exist reported higher variability with this measure due to factors that modulate sustained contractions such as motivation and muscular fatigue (59). Despite these limitations, impaired endurance capacity and reduced neuromuscular efficiency of the cervical musculature is a commonly reported finding in patients with NP (6, 64, 163). Given the conflicting evidence, there is no consensus among clinicians and researchers regarding the association between NP and neck strength/endurance measurements. However, there appears to be agreement on the value of these variables to determine training dosage and to document rehabilitation efficacy (58, 59).

As previous authors have highlighted, one of the weaknesses surrounding the literature examining cervical strength is the lack of data regarding the reliability of the measures (58, 59, 95). Historically many authors have evaluated different devices using relative reliability measures such as Pearson’s r and/or Intra-class correlation coefficients. One of the drawbacks of using these measures is their sensitivity to heterogeneous samples, as highlighted by Dvir and Prushansky (58). Research on a heterogeneous cohort could potentially inflate the correlation values due to the between-subjects variability relative to the total observed variability in the sample (95). Secondly, the authors emphasize the inability to conclude from these relative reliability measures as to whether the treatment group has improved or deteriorated (58). To circumvent these limitations, the current recommendation is to use absolute reliability parameters such as standard error of measure (SEM) and minimal detectable change (MDC). SEM is used to determine the amount of variation or spread in the measurement errors for a test, while MDC allows the researcher to determine whether or not change (decrements or improvements) in performance has occurred as the result of an intervention or seasonal exposure to loading (58).

Research has been conducted in rugby union to examine cervical strength in both professional (76, 88) and youth rugby players (75). These studies were conducted in a seated position which is consistent with previous work evaluating neck strength in football players
(91), fighter and helicopter pilots (6), wrestlers (178) and the general population (95, 165, 175). Isometric neck strength and endurance evaluated in seated (95, 165, 175), standing (165), prone (163) and supine (163) postures has reported reliability indices ranging from good to excellent. Justification for these testing postures was based on the researchers’ desire to isolate the cervical musculature, and to also limit contributions from accessory muscles. In rugby, loading of the cervical spine typically occurs when players are involved in tackling, scrummaging, rucking or during collisions, all of which rarely occur when a player’s cervical spine is in a vertical position. In order to address this issue the candidate designed a more functionally relevant testing apparatus to measure isometric neck strength and endurance. This device placed the individual in a simulated contact position with the neck in a neutral horizontal position (Part I). In a healthy male population, this testing apparatus provided reliable measures (ICC $^{(3,1)} = 0.91$ to $0.98$) of peak force for repeated maximal voluntary contractions (MVC) in Ext, Flx, and LtFlx and RtFlx during a single testing session. However, the reliability of the testing apparatus has not been examined over time.

4.9 Part II: Research Questions

The purpose of this study was to examine the reliability of repeated measurements of neck strength and endurance over three testing sessions using a testing apparatus functionally relevant for collision sports. In this simulated contact posture, isometric peak force and endurance values for Flx and Ext were analysed to examine variations in patterns or trends that may exist across the repeated sessions for the two directions.

4.10 Part II: Methods

4.10.1 Ethics

Institutional ethical approval was obtained from the University of Otago Human Ethics Committee (Appendix D) and the Ngāi Tahu Research Consultation Committee (Appendix E).

4.10.2 Participants

Healthy male and female participants were recruited from a university student population. In order to maximize variability, females were included in this particular study, thus permitting the use of normalization techniques. Participants were excluded if they engaged in collision sports or self-reported receiving treatment in the last three months for any of the following:
(a) musculoskeletal injury to the cervico-thoracic spine, (b) cervicobrachialgia, (c) shoulder pain during neck movement or (d) radiating pain when overloading the cervical spine (40). Informed consent was provided by all participants (Appendix F).

4.10.3 Testing apparatus

A custom built device was designed to assess participants in a simulated contact posture that was deemed functionally relevant for collision sports such as rugby. The apparatus included (a) an adjustable padded support bench, (b) adjustable forearm bench and (c) a vertical pole mount with a headpiece (Figure 4.2). In this posture, the neck was placed in a neutral horizontal position while the participant adopted a tackle stance with their chest and forearms supported by benches to standardize position between sessions. A detailed description of the apparatus is provided elsewhere (Chapter 4: Part I). In order to establish the reliability of this apparatus over time, testing was conducted on three non-consecutive days (≥ 48 hrs between sessions). All equipment adjustments for individuals were recorded to allow for standardization of position over the three testing days. Repeated sessions for each participant were conducted by the same researcher at approximately the same time of day (59). Participants were instructed to continue their normal routine between testing sessions.

4.10.4 Experimental procedures

Body mass, stature and neck circumferences were measured during the first testing session. Neck circumference was measured and the warm-up performed following the same protocol outlined in Part I Section 4.4.4 of this Chapter. Following this the participant was asked to assume the simulated tackle stance in the device and the resting weight of the head on the four force transducers was recorded. These values were subsequently subtracted from the maximal values achieved during each MVC to account for resting pressure on the force transducers.

Peak force assessment. Immediately preceding data collection, participants were familiarised with the apparatus and tasks by performing two or three submaximal contractions and then a single unrecorded maximal voluntary contraction (MVC) in each tested direction. A single isometric MVC was then performed for both Ext and Flx in a randomly determined order that varied for each participant. Instructions regarding the performance of each MVC were as described in Part I Section 4.4.4 of this Chapter. The
maximum force achieved during the 5 s was recorded as the MVC. Verbal encouragement was provided during each MVC (6, 59). Peak force was recorded in Newtons (N).

**Submaximal endurance assessment.** Participants performed a single submaximal endurance trial for both directions following the same testing order as the peak force assessment. The format for the endurance trials required participants to: (a) maintain an isometric force at 70 ± 5% of their MVC force for 7 s, and (b) increase isometric force to 90 ± 5% of their MVC and maintain that level for 4 s (Figure 4.4). Participants were then given a 4 s timeframe in which to adjust their force requirements. This cycle was repeated with the maintained force never falling below 70 ± 5% of MVC for a maximum of 3 min or until the force output fell below the respective 70 ± 5% MVC thresholds for more than 4 s. Visual feedback of force production was provided throughout endurance trial via a laptop screen, positioned so the screen was in the participant’s direct line of sight. Verbal encouragement was provided throughout each endurance trial. A rest interval of 2 min was observed between each endurance trial to allow the participant to recover.

![Figure 4.4: Sample of an Ext endurance trial to volitional fatigue. Participant failed to attain 90% ± 5% MVC level within the 4 s timeframe and the test was terminated at 48 s.](image-url)
**Endurance trial data processing.** Endurance trials were analysed to determine the area under the force curve (AUC) and the times to fatigue (TTF) for Ext and Flx. The AUC was used as an index of cervical muscle fatigue during each endurance trial and was calculated using MATLAB (MathWorks®, Natick, MA) and the trapezium rule method. The MVC peak forces recorded during the start of season assessment were used to calculate the 70% and 90% MVC target forces for the end of season endurance trials. This recording allowed for direct comparisons between the start and end of season assessment periods to determine whether changes in endurance performance had occurred. In order to directly compare the AUC across sessions and for each direction, the AUC was calculated using a normalized force curve. The force curve was normalized using the start of season’s MVC value set to 1.0 to produce a %MVC-s value (%AUC). The TTF was the length of time in seconds the submaximal force was maintained prior to terminating the test by either reaching the 3 min mark or when a participant dropped below the 70 ± 5% mark for more than 4 s (5, 6).

### 4.10.5 Statistical analysis

Descriptive statistics (mean and SD) were calculated for each direction (Ext and Flx) and session (1-3). Previous research exploring the relationship between isometric neck peak force and gender has reported that males were stronger than females (165, 167, 175). Given the expected peak force gender difference in the data, the decision was made to normalize the force data. To control for this potential main effect for gender, Pearson product correlations were conducted with the continuous anthropometric variables measured such as: age, weight, height and neck girth (Table 4.3) (75). Potential predictive variables were selected if their bivariate significance was less than 0.05; weight, height and neck girth met that criteria. A mixed model ANCOVA was then conducted for each of the strength and endurance variables using weight, height and neck girth as covariates to develop predictive models (4). The resulting models highlighted neck girth as the only variable which contributed to the variance in the results once the confounding influence of the other variables had been controlled for. A second definitive model was constructed with only neck girth used as a covariate for each measured variable, and the resulting formulae were used to normalize the respective strength and endurance variables to account for the variability due to the differences in neck girth. A 3(session) x 2(direction) mixed model ANOVA was used with the normalized data to examine the main effects for session and direction and to determine whether or not any interaction existed. Where appropriate, Bonferroni pair-wise comparisons were used to explore the significant interaction effects (Part I).
Table 4.3: Bivariate correlation of peak force and endurance variables with anthropometric measures

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Peak force</th>
<th>% AUC</th>
<th>Time to fatigue</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Ext</td>
<td>Flx</td>
<td>Ext</td>
</tr>
<tr>
<td>Age</td>
<td>r</td>
<td>-0.04</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>0.78</td>
<td>0.32</td>
</tr>
<tr>
<td>Neck girth</td>
<td>r</td>
<td>0.88</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>0.01*</td>
<td>0.01*</td>
</tr>
<tr>
<td>Height</td>
<td>r</td>
<td>0.31</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>0.02*</td>
<td>0.01*</td>
</tr>
<tr>
<td>Weight</td>
<td>r</td>
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<tr>
<td></td>
<td>p</td>
<td>0.01*</td>
<td>0.01*</td>
</tr>
</tbody>
</table>

* Indicates correlation is statistically significant at the 0.05 level

To determine the relative reliability of the device and testing procedures, average and single measure Intra-class Correlation Coefficients (ICC_{(3,1)}) and 95% confidence intervals (95% CI) were calculated using the MVC values from the 3 test sessions for each direction. The ICC were evaluated using the following criteria: poor ICC < 0.50, moderate 0.50 < ICC < 0.70, good 0.70 < ICC < 0.90, and excellent ICC > 0.90 (163).

Absolute reliability was determined using the measurement error associated with a single MVC measurement, calculated as the SEM using the formula: SEM = SD x √(1 – ICC).(286) The SD value used was the SD of the three test sessions combined and the ICC value was the 2-way random model single measure consistency value. This ICC value was chosen because it is a reflection of the error associated with a measurement collected at a single point in time (286). The error associated with multiple measures of maximum strength for each direction was calculated as the minimal detectable change (MDC). The MDC is the smallest amount of change in the MVC scores that can be considered actual change that exceeds error in the measurement. It was determined using the formula: MDC = 1.96 x √2 x SEM and was calculated to the 95% confidence level (287). SPSS 19.0 (IBM SPSS Statistics, Somers, N.Y.) was used for all statistical analyses, and the criteria for statistical significance was set at α = 0.05.
4.11 Part II: Results

Twenty four participants (14 males and 10 females) were recruited. Due to scheduling conflicts, only 20 participants (13 males and 7 females) completed all three testing sessions. Anthropometric values are reported in Table 4.4. Descriptive statistics for peak force and endurance values for Ext and Flx are presented in Table 4.5. Using the raw MVC data, a 3(session) x 2(direction) mixed model ANOVA revealed a statistically significant main effect for gender $F(1,18)=27.64, p<0.01$, indicating that the males were stronger than the females, justifying the normalization of the data.

<table>
<thead>
<tr>
<th>Gender</th>
<th>Age (yrs) Mean</th>
<th>SD</th>
<th>Weight (kg) Mean</th>
<th>SD</th>
<th>Height (cm) Mean</th>
<th>SD</th>
<th>Neck girth (cm) Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>26.86</td>
<td>6.76</td>
<td>80.66</td>
<td>9.40</td>
<td>178.26</td>
<td>7.07</td>
<td>38.87</td>
<td>2.10</td>
</tr>
<tr>
<td>Females</td>
<td>25.00</td>
<td>1.53</td>
<td>66.28</td>
<td>12.13</td>
<td>170.76</td>
<td>8.70</td>
<td>33.01</td>
<td>2.64</td>
</tr>
</tbody>
</table>

A 3(session) x 2(direction) mixed model ANOVA for the normalized peak force variables revealed a significant main effect for session, $F_{(2,38)}=6.27, p<0.01$, and direction, $F_{(1,19)}=165.57, p<0.01$, but no statistically significant interaction, $F_{(2,38)}=0.17, p=0.84$. Examination of the residuals suggested that there was a distributional difference between the two directions and that the variance between directions was slightly larger than between sessions, thus violating the normality and homogeneity assumptions of the ANOVA. Thus, a one-way repeated measure ANOVA was conducted for both Ext and Flx. The Ext direction when examined yielded a statistically non-significant effect for session, $F_{(2,38)}=1.632, p=0.21$, while Flx was statistically significant for session, $F_{(2,38)}=5.175, p=0.01$. Further post-hoc analysis of the main effect for Flx revealed that force production in session 1 (115.27 ± 38.85 N) was lower than session 3 (126.45 ± 41.79 N) ($p=0.03$), potentially indicating that learning had occurred.

Examination of the %AUC revealed no statistically significant main effect for session, $F_{(2,38)}=2.93, p=0.07$, or interaction between session and direction, $F_{(2,38)}=0.86, p=0.43$. However, a statistically significant main effect for direction was found, $F_{(2,38)}=6.96, p=0.02$, indicating that Flx (93.55 %AUC) was superior to Ext (61.42 %AUC). The normalized TTF data produced statistically significant main effects for both session, $F_{(2,38)}=3.71, p=0.03$, and direction, $F_{(1,19)}=6.26, p=0.02$. Post-hoc analysis of the session main effect detected no
difference across the three sessions. This result could be explained by the lower power of the post-hoc test compared to the ANOVA test. However, consistent with the %AUC data, the TTF Flx values (124.96 s) were longer than the TTF values for Ext (86.13 s). The change in TTF for each direction across the three sessions was consistent, as indicated by the lack of statistical significance for the interaction effect, $F(2,38)= 0.82, p= 0.45$.

The average peak force measure and endurance ICC$_{(3,1)}$ values for Flx and Ext were all excellent (0.92-0.98). The peak force single measure ICC$_{(3,1)}$ value for Ext was considered good (0.80), while flexion ranked as excellent with a value of 0.91. The endurance variables showed a similar trend with the ICC$_{(3,1)}$ values for Ext ranging from good to excellent (0.85 to 0.95), and the flexion values all excellent (0.91 to 0.94). For peak force, the greatest SEM and MDC was achieved for Ext (15.27 N and 42.33 N), while flexion produced lower values (11.27 N and 31.23 N). The opposite trend was displayed for the submaximal endurance sessions with flexion producing higher values than Ext. Absolute and relative reliability values are also reported in Table 4.5.
Table 4.5: Normalized peak force (N) and endurance values over the three trials

<table>
<thead>
<tr>
<th>Direction</th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
<th>Combined</th>
<th>ICC(_{(3,1)})</th>
<th>Single</th>
<th>Average</th>
<th>95% CI</th>
<th>SEM</th>
<th>MDC</th>
</tr>
</thead>
<tbody>
<tr>
<td>MVC (N)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ext</td>
<td>Mean</td>
<td>223.08</td>
<td>223.67</td>
<td>230.93</td>
<td>225.89</td>
<td>0.80</td>
<td>0.92</td>
<td>0.84-0.97</td>
<td>15.27</td>
<td>42.33</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>38.65</td>
<td>32.77</td>
<td>31.29</td>
<td>34.24</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flx</td>
<td>Mean</td>
<td>115.27</td>
<td>119.00</td>
<td>126.45</td>
<td>120.24</td>
<td>0.91</td>
<td>0.97</td>
<td>0.94-0.99</td>
<td>11.27</td>
<td>31.23</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>38.85</td>
<td>33.94</td>
<td>41.79</td>
<td>38.19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% AUC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ext</td>
<td>Mean</td>
<td>54.42</td>
<td>67.65</td>
<td>56.10</td>
<td>59.39</td>
<td>0.95</td>
<td>0.98</td>
<td>0.96-0.99</td>
<td>34.30</td>
<td>95.09</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>44.27</td>
<td>57.48</td>
<td>53.17</td>
<td>51.64</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flx</td>
<td>Mean</td>
<td>86.23</td>
<td>78.43</td>
<td>93.19</td>
<td>85.95</td>
<td>0.94</td>
<td>0.98</td>
<td>0.95-0.99</td>
<td>41.90</td>
<td>116.13</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>71.47</td>
<td>53.97</td>
<td>71.02</td>
<td>65.49</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time to Fatigue (s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ext</td>
<td>Mean</td>
<td>56.26</td>
<td>51.83</td>
<td>52.08</td>
<td>53.39</td>
<td>0.95</td>
<td>0.98</td>
<td>0.97-0.99</td>
<td>8.58</td>
<td>23.78</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>38.30</td>
<td>38.90</td>
<td>42.78</td>
<td>39.99</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flx</td>
<td>Mean</td>
<td>82.58</td>
<td>76.69</td>
<td>73.09</td>
<td>77.45</td>
<td>0.93</td>
<td>0.98</td>
<td>0.95-0.99</td>
<td>12.53</td>
<td>34.73</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>48.53</td>
<td>45.78</td>
<td>49.82</td>
<td>48.04</td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>
4.12 Part II: Discussion

This study examined the test-retest reliability of an apparatus (and protocols) designed to measure neck isometric strength and endurance in a simulated contact position. This posture is functionally relevant to collision sports where the spine is primarily loaded in an approximately horizontal position. The majority of previous research has been conducted in a seated position with the neck in a vertical posture (75, 76, 88). Within our experimental cohort, the relative reliability measures over three separate testing sessions ranged from good to excellent (ICCs 0.80-0.95). Previous work examining SEM values for the cervical musculature in seated and standing position reported that values below 21 N indicated small variation among participants (165). The SEM for the peak force and TTF results were all well below 21 N, indicating small variations in these measures for the cohort over the three sessions (165). MDC scores were also determined for each of the measured variables. These values will enable future researchers/clinicians/coaches to evaluate neck rehabilitation programs or individual training progress. Taken together these findings support the reliability of this novel testing apparatus and experimental protocol for the repeated assessment of neck strength and endurance.

The peak forces recorded in the current study demonstrate a strength pattern similar to previous research conducted with this testing apparatus (Part I). These results are also comparable to neck strength assessments that have been conducted in seated (76, 88, 95) and standing positions (165), where Ext peak force tested stronger than Flx. The superior peak force recorded for Ext reflects the larger postural role of these muscles and is further highlighted by the larger cross-sectional area of the extensor muscles (39, 175). For the current study, the average Flx:Ext ratio for peak force values was 1:1.88. Over the three sessions, this ratio ranged from 1:1.83 to 1:1.94. These ratios fall between the 1:2.0 ratio previously reported for females and 1:1.43 ratio for males (175). As peak force values for Ext tested stronger than Flx, the force requirements for the subsequent endurance trials were substantially higher for Ext than Flx. However, both the Flx and Ext endurance trials were standardized using a percentage of peak force for the respective directions allowing comparison to be made between the two. Analysis of the %AUC and TTF for the two directions revealed that endurance was greater in the Flx direction than Ext. This difference in endurance capacity could be explained by variation in the muscle fibre types between the ventral and dorsal muscle of the neck, indicating a larger proportion of Type I fibre in the ventral muscle.
The neck is impulsively loaded throughout a rugby game when players are required to tackle, ruck, scrum, and/or maul. Combined with the fact that the majority of neck injuries occur later in the game and as the season progresses, these results implicate muscle fatigue as a potential risk factor (30). However, cervical muscular endurance has not been examined in rugby or other collisions sports. Previous work examining cervical endurance in helicopter pilots required individuals to sustain a 70% load for a maximum of 3 min (5, 6, 71). However, to replicate the impulsive loading that occurs during a rugby game in a simulated environment, we designed a protocol that required participants to repeatedly sustain 70% of their MVC force for 7 s. The 7 s timeframe was based on time motion analysis data (141) for forwards who are at a higher risk of neck injuries (30) and NP (44). In Super 15 rugby forwards spend an average of 7.1 ± 2.7 s in static play, defined as rucking, mauling or scrumming, interspersed by running, jogging or walking (141). To simulate this static play, a protocol of repeatedly isometrically loading the neck at 70% MVC for 7 s followed by a 4 s rest period was piloted with amateur rugby players (n = 12), but most failed to reach volitional fatigue within the 3 min period. To induce fatigue within 3 min, the protocol was adjusted to replace the 4 s rest period with a sustained 90% MVC contraction. This modification required participants to cycle between 70% and 90% of their MVC for a maximum or 3 min or until fatigue occurred.

In our cohort, the male participants tested stronger than the females, which is consistent with previous findings for gender neck strength differences (165, 167, 175). In other studies with similar aged cohorts tested in a seated position, males were 14.18-38.89% stronger than females for Ext and 58-75.6% for Flx (167, 175). The percent difference between males and females for the current study were substantially larger with males testing 75.80% stronger for Ext and 136.21% for Flx. These differences may be reflective of the novel testing position and/or the fitness levels of the participants.

To check whether the gender differences were merely reflecting body size differences, bivariate Pearson’s correlations were generated. The results revealed that weight, height, and neck girth were all positively correlated to peak force. Consistent with these results, a recent study examined the age-related differences in the neck strength of male adolescent rugby players and found that Ext MVC was positively correlated with age, height, and weight of the participant but not neck girth (75). This discrepancy with our findings on the correlation between neck girth and peak force could be attributed to the difference in age range between the two studies. As the age range of our participants was relatively small, this variable was
not correlated to any of the measured variables. Additionally, research has indicated that correlations between neck strength and other anthropometric variables are higher in athletes than the general population (166, 288). Other researchers have reported positive correlations between neck musculature peak force, weight (166, 167) and height (166) for male participants. Research with female participants has provided varying results; a positive correlation for peak force and height (166) contrasting against a negative correlation for weight and peak force (167). However, none of the studies exploring the relationship between anthropometric variables and neck strength in males and females measured neck girth (166, 167, 171).

For the %AUC and TTF values, neck girth and weight were negatively correlated, indicating that the heavier individuals with the largest neck girths had the smallest endurance values. The opposite was true for height; the taller the individual, the greater their %AUC and TTF scores, with the exception of Flx TTF which were negatively correlated with height.

Valid comparisons of muscle strength and endurance between individuals necessitate the need for data normalization (4). Given the small sample size of the current cohort and the significant gender differences for peak force, TTF and %AUC, we elected to normalize the data. One of the commonly used methods for normalization is the computation of percentages or size-specific indices. Unfortunately, these ratios seldom eliminate the influence of body size on the measured physiological variable and introduce error into the statistical analysis. Packard and Boardman (4) state that a superior alternative is the use of graphical representation and analysis of covariance, which employs least-squares regression to eliminate the influence of body size on the physiological data. Using this method, the anthropometric parameters that were correlated with peak force and endurance were evaluated to determine their effect on the normalization of these physiological parameters. The examined models indicated that using neck girth to scale peak force and endurance was the most effective anthropometric parameter for normalization (4). Previous research has been conducted that normalized cervical peak force to body mass index, however, no information was provided regarding their method of normalization (166).

One of the drawbacks of relative reliability statistics such as ICC values is their inherent sensitivity to sample heterogeneity. By normalizing the data, we have minimized this confounding factor by removing the variability attributed to neck girth, which generated a more homogenous cohort. For the ICC values, we have reported two variables: the single and
the average measures. The single measure ICC is an index of reliability for a single session, while the average measures ICC is an index of reliability for the values across the three sessions averaged together. When comparing the average ICC\(_{(3,1)}\) between the current study (three separate sessions: 0.92 and 0.97), and previous work with this device (three repeated trials during a single session: 0.91 and 0.97) all scores can be categorized as excellent for both Ext and Flx respectively (Part I). In contrast, the single ICC\(_{(3,1)}\) results for Ext differ with the single session study reporting excellent values, (Part I) while in the current study the value decreased to good (0.80). These results indicate an increase in the variability of the Ext scores when MVC are conducted over repeated sessions. This finding may be explained by small variations in technique or body position employed by participants over the three sessions. The opposite pattern was observed for the flexion direction with the Part I study reporting ICC values of 0.86, and the current study 0.91, indicating a more consistent performance across sessions. Analysis of the endurance variables demonstrates excellent single measure ICC\(_{(3,1)}\) values ranging from 0.93-0.95 for the %AUC and the TTF. Fewer studies have examined the submaximal endurance of the neck musculature (59) and most of this research has focused predominantly on the deep cervical flexors through the use of the cranio-cervical test or supine testing of the cervical flexors via resisted contractions or head lifts (59, 163). Edmondston et al. (163) examined the endurance of the cervical flexors using a supine head lift, and the cervical extensors using a prone isometric hold using 2 kg weight, and reported similar ICC values of 0.93 and 0.88, respectively. These findings suggest that the reliability of the endurance protocol employed in the current study is similar to previously published endurance tests for the neck.

Measurements of cervical strength are of clinical value for the determination of training dosage and/or to document rehabilitation progress (58). Therefore, SEM and MDC provide valuable information as they allow researchers and clinicians to determine whether meaningful changes in muscular performance have occurred. When an experimental protocol or testing apparatus is used to evaluate changes in peak force or endurance over time, measurement error should be as low as possible. In this context, SEM indicates the level of agreement between repeated trials (163). For the current study, the SEM values for peak force are well below 21 N (Ext:15.27 N and flexion:11.27 N), the value suggested to indicate small variation among the subjects for neck muscle peak force over repeated trials (165). These findings are consistent with previous research that has been conducted using this device with SEM value of 15.69 N for Ext and 19.04 N for Flx (Part I). The variation in SEM
results for Flx between the two studies can be attributed to the lower single measure ICC\(_{(3,1)}\) 0.86 value for the repeated MVC study, indicating that there was more variation between MVCs repeated three times within a session that compared to a single MVCs performed on three separate occasions. This variation could potentially be explained by possible muscular fatigue when MVCs are repeated within a single session. When comparing the SEM measures for the current study, Ext demonstrated more variability than Flx. For Ext, the adoption of slightly modified body positions could potentially alter peak force production, while the capacity to do this would be limited for Flx. For the endurance variables, the SEM for the TTF for Ext (8.58 s) and Flx (12.53 s) were small, indicating low variability; however, the %AUC values were substantially higher (Ext: 34.30 and Flx: 41.90). This result is to be expected given that the endurance protocol was designed to be demanding and required participants to maintain 70% and 90% of their MVC with minimal fluctuation in force. An individual’s ability to maintain these force levels would be limited and this fluctuation in force would alter their %AUC values. Research on the endurance characteristics of the cervical musculature has focused primarily on TTF (Part I)(163) with no consideration of AUC force data, thus precluding comparisons with this variable. The one study that reported TTF SEM values for endurance testing focused on low submaximal loads in a supine position for Flx, and a prone position for Ext (163). Although their testing protocol was substantially different from the current study, they reported a larger SEM for their neck extensor test (25.8 s) than the flexor test (6.4 s), while those in the current study were relatively similar. This discrepancy would suggest that the endurance protocol used in the current study imposed similar metabolic loads on both the cervical flexors and extensors.

Although SEM provides insight into the reliability of a test, the more critical measure from a program evaluation perspective is the MDC, which reflects the level of change required in a measured variable to be considered greater than measurement error (95, 163). Our MDC results for Ext and Flx peak force indicate that improvements in performance of more than 18.7% and 26.0% respectively, would be considered clinically significant. Research that has calculated SEM using the same formula reported Ext values of 17.1% for females and 25.1% for males and Flx values of 15.1% and 23.2% for females and males, respectively (165). One study using typical error values to calculate SEM for a highly active male cohort reported a 12.2% change for Ext and 17.4% for Flx (95). Although these values are lower than reported in the current study, they demonstrate a similar trend with Flx requiring a larger percentage change than Ext. Our values approximate those reported for the general population, (165) but
are higher than those of highly active males (163). Unfortunately, other published data were not available to compare the % performance improvement for %AUC (Ext: 160.1%, Flx: 135.1%), however, when compared to the peak force and TTF values (Ext: 44.5%, Flx: 44.8%), these were substantially larger. As noted, this finding was expected given each participant’s between trials variability in maintaining isometric loads. In a previous study that assessed neck flexor endurance, an MDC of 35.2% was reported (163) which is smaller than the value obtained in the current study. However, in the same study the neck extensor test MDC value was 50.2% (163). While both studies examined isometric contractions of the neck flexors and extensors, the relative load used in the present study was substantially higher; this may explain the observed differences.

4.13 Part II: Conclusion

Reliably measuring neck musculature strength and endurance is necessary to determine whether they play a role in reducing the severity or risk of neck injury in collision sports such as rugby. The results of this study have demonstrated that these variables can be measured with an acceptable degree of relative reliability over repeated testing sessions using a customized testing apparatus and protocol. This protocol and testing apparatus thus can be used to document the effectiveness of a training intervention or to track progress during a player’s rehabilitation from a neck injury over time. Peak force data recorded over the repeated trials demonstrated findings consistent with previous research. The absolute reliability SEM and MDC scores established in this study are of clinical value for the interpretation of future research into the longitudinal assessment of neck strength and endurance over a season. Moreover, reliably measuring neck performance allows for the evaluation of a neck specific intervention.
Chapter 5

Monitoring of: Neck Strength, Endurance, Neck Pain and Neck Stiffness over a Season in Amateur Rugby Players and Controls
Chapter 5 – Neck Function Over a Season

Chapter 1: Introduction

Chapter 2: Review of the Literature

Chapter 3: The Long-term Consequences of Neck Injury in Rugby

Chapter 4: Experimental Protocol and Design of the Fixed Frame Dynamometer to Assess Neck Strength and Endurance in a Simulated Contact Posture

Part I: The Reliability of Repeat Isometric Neck Strength Testing in a Simulated Contact Posture

Part II: Reliability of Repeated Trial Isometric Neck Strength and Endurance Testing in a Simulated Contact Posture

Chapter 5: Monitoring of: Neck Strength, Endurance, Neck Pain and Stiffness over a Season in a Cohort of Amateur Rugby Players and Controls

Chapter 6: Design of a Neck Specific Exercise Intervention for Rugby

Chapter 7: An Examination of a Neck Specific Intervention in a Professional Rugby Team Relative to a Control

Chapter 8: Summary, Strengths and Limitations, Future Research Directions and Conclusions
5.1 Introduction

Rugby is a collision sport characterized by high-speed collisions between players that can predispose them to injuries, particularly to the head, neck and spine (30, 34, 87). While there is potential for permanent neurological damage or death as a result of acute catastrophic cervical spine injury (18, 20, 29, 97, 111, 255), the majority of neck injuries sustained in rugby are classified as minor in severity (30, 34, 36). It has been proposed that enhanced cervical strength may help prevent or mitigate the severity of minor neck injuries for collision athletes (53, 54, 56, 57, 90). Prior to the implementation of an intervention, the literature regarding the development of preventative measures has highlighted the importance of identifying the factors and mechanisms which play a role or influence the occurrence of the observed sport injury (21). Currently, there is no research monitoring typical neck strength and endurance fluctuations over the season in amateur rugby players.

One of the primary symptoms of minor neck injuries is neck pain (NP) (64). The prevalence of NP in amateur rugby has been reported to be high (44). While NP has not been examined at the professional level, it would be expected that the level of reported pain would be higher than for amateurs, given professional’s increased frequency of neck injuries (30, 46). Previous work with non-athletic populations has documented reduced cervical strength and endurance in the cervical musculature for individuals with NP (121, 122). Additionally, individual with NP have been found to display the following neuromuscular patterns: greater fatigability of the superficial prime movers, impaired neuromuscular efficiency of the superficial prime movers and impaired recruitment of the deep cervical flexors (5, 61, 67-70, 123, 125, 126). Although these neuromuscular patterns have not been examined in rugby players, it is feasible that similar strength and endurance patterns exist for players who have sustained minor neck injuries.

In the sport injury literature, the “Sequence of Prevention” is a phrase that has been coined to describe measures taken to prevent injuries in sport (21). The first step in this framework is an examination of the injury surveillance data (21). Rugby neck injuries range from 0.5 to 10.58 injuries/1000 player-hours for professional players (30, 46, 84), 2.9 injuries/1000 player-hours for amateur players (36), and 6.1 injuries/1000 player-hours for youth rugby players (34). Phase 2 of the model explores factors and mechanisms which may influence the occurrence of neck injuries. Research has identified a number of potential mechanisms and factors that may influence the occurrence of neck injuries during impact events ranging from:
(a) the phase of play (20, 24, 26, 27, 29, 30, 35, 36, 87), (b) playing position (20, 24, 27, 30, 36, 52, 140), (c) head position/posture during contact (25, 26, 130, 232), (d) speed of contact (54, 130, 153-155, 157), (e) awareness of impending collision (157, 158), (f) co-contraction of agonist and antagonist muscles (130, 157), (g) neck girth (162, 173), and (h) neck strength (89-92). The focus of this study is the role that cervical musculature may play in prevention and/or mitigation of these injuries.

Quantification of cervical strength in rugby players has been largely neglected, with only a limited number of published studies (74, 76, 88). One study documented isokinetic cervical strength in 189 South African male provincial level rugby players. Peak torque values for flexion (Flx), extension (Ext), left (LtFlx) and right lateral flexion (RtFlx) were examined. Second row players had the highest peak torque values for Flx and LtFlx, front row players for Ext, and back row players for RtFlx. When position specific data for the forwards were compared, the only statistically significant difference was front row forwards had greater extensor strength than back row players. Peak torque values were greater for forwards when compared to backs. However, when these peak torque values were normalized for body weight, the only differences found were for Ext and RtFlx between the forwards and backs (76). While this study provides a snap shot of the strength profiles of players at various positions it provides no indication of what happens to these strength values over a season. In addition, there are methodological issues associated with the biological and mechanical axis of rotation when evaluating peak torque in the cervical region which raises questions regarding the reliability of the results (58, 59).

In a methodological review of cervical strength, isometric assessment was endorsed as the most reliable evaluation tool, presenting the smallest level of injury risk to the participant (58, 59). A recent study examined the reliability of assessing isometric cervical strength using a handheld dynamometer (74). The authors assessed strength in 25 academy-level players (16 forwards, 9 backs) on two separate occasions. During each testing session, three MVCs were conducted for Flx, Ext, LtFlx and RtFlx and an average peak force was calculated. Although forwards demonstrated a trend towards greater neck strength, the only statistically significant difference was for Ext (forwards: 637.10 N and backs: 537.87 N) (74). While the mode of assessment used in this study was simple and is widely commercially available, the examiner must provide resistive force during testing and participants must be stabilized in order to perform an isometric contraction (58). Given the high prevalence of degenerative changes in rugby players’ cervical spines and the likely variability of examiner-applied force, (47) the
potential for injury during assessment may be high. Relative (ICC: 0.80-0.85) and absolute reliability (SEM: 18.49-40.57 N) values for this study for the four directions were ranked from good to excellent (74) Although this method of evaluation allows for the quantitative assessment of peak force, other authors have suggested its reliability and validity are vulnerable to examiner bias (58, 59).

The most common method of isometric cervical strength assessment is a fixed-frame dynamometer (58, 59), which has been used to examine professional (73, 88) and youth rugby players (75). At the professional level, two studies have examined the effectiveness of a team neck strengthening intervention on peak Ext, Flx, LtFlx and RtFlx (73), and following injury to a loose-head prop (88). While monitoring is essential to evaluate the effectiveness of a program, currently there is no ecological research measuring neck strength or endurance over a season of rugby. The present study sought to isometrically monitor neck strength, endurance, and self-reported NP and NS in amateur rugby players and healthy controls over the length of a season. Neck strength and endurance were assessed in a simulated contact posture using a custom-made fixed frame dynamometer whose reliability has been established previously (Chapter 4).

5.2 Research Questions

The primary purpose of this study was to monitor cervical strength and endurance over a season in a cohort of male amateur rugby players (forwards and backs) relative to a healthy male control population. In conjunction with measures of strength and endurance, changes in current, average, and worst NP and NS were monitored over a competitive season in the rugby cohort and controls. It is essential to monitor the functional capacity of these muscles in order to observe improvements or decrements resulting from exposure to a season of rugby or a targeted intervention. The secondary purpose was to evaluate the relative and absolute reliability of the measures to determine whether changes in performance had occurred over the season.

As the injury surveillance literature indicates that forwards sustain proportionally a higher number of neck injuries when compared to backs (20, 27, 30, 52) and previous research looking at neck muscle peak torque values has reported strength differences between these two groups, the amateur rugby cohort was grouped by position into forwards and backs.
5.3 Methods

5.3.1 Research design

This longitudinal study measured neck strength, muscular endurance, NP and NS in a cohort of amateur rugby players (forwards and backs) over a 20 week season, relative to a healthy control group who did not participate in collision sports. Changes in neuromuscular and perceived dysfunction in the forwards and backs were compared separately.

5.3.2 Ethics

Institutional ethical approval was obtained from the University of Otago Human Ethics Committee (Appendix D) and the Ngāi Tahu Research Consultation Committee (Appendix E). All participants provided informed consent prior to participating (Appendix I).

5.3.3 Participants

Due to the expected difficulty in recruiting and retaining participants for the duration of the season, a pragmatic approach was taken towards recruitment and no formal power calculations were performed to determine the ideal sample size. A sample of convenience was recruited with participants from four male premier grade amateur rugby teams in Dunedin, New Zealand (n= 58). Premier club rugby is the highest level of non-representative, non-professional rugby in New Zealand. Meetings with the head coaches and physiotherapists for each team outlined the goals and the time commitments expected from participants in the study. Healthy male control (CON) participants (n= 17) were recruited from the undergraduate student population through presentations during classes and via an e-mail announcement. The goals of the project and the requirements for testing were clearly outlined to all members of the four participating teams and the controls. Following this, informed consent was obtained from individuals who volunteered to participate. Participants were excluded if they had received treatment in the previous three months for any of the following: (a) musculoskeletal injury to the cervico-thoracic spine, (b) cervicobrachialgia, (c) shoulder pain during neck movement or (d) radiating pain when overloading the cervical spine (40, 214). Volunteers from the rugby cohort were grouped into forwards (F) and backs (B), and were excluded from participating if they were not currently playing rugby. Participants for the control group were excluded if they were currently playing any type of collision sports (e.g. rugby union, rugby league, ice hockey).
5.3.4 Rugby season

The rugby season consisted of two field-based training sessions per week and weekly games, and extended for a period of 20 weeks (April to July). Assessments were conducted at the start (weeks 1 to 4) and the end of season (weeks 17 to 20) see Figure 5.1. Both assessment periods spanned four weeks so that all participants (F, B and CON) could be tested within the same timeframe. Participants were instructed to continue their normal training routine and/or activities between testing sessions.

Figure 5.1: Outline of the testing schedule

5.3.5 Testing apparatus

A custom designed device was built to assess participants in a simulated contact posture that is a functionally relevant body position for collision sports such as rugby. The apparatus included: (a) an adjustable padded support bench, (b) adjustable forearm bench and (c) a vertical pole mount with a headpiece (Figure 4.2). The neck was placed in a neutral horizontal position while the participant adopted a simulated contact posture with their chest and forearms supported by benches. A detailed description of the apparatus is provided in Chapter 4. All equipment adjustments for individuals were recorded to standardize the body position between the start and end of season assessments.

5.3.6 Experimental protocol

The candidate conducted all assessments at approximately the same time of day. During the initial session, each participant’s body mass (kg), stature (cm) and neck circumference (cm) were measured (Appendix G). At the end of season assessment rugby participants completed a questionnaire on their rugby career, playing position, number of games played over the season, number of years total of rugby played, handedness, whether they completed neck specific exercises, and their tackle shoulder preference (Appendix J). Prior to any strength measurements, all participants were asked to rate their current levels of NP and NS, and average and worst levels over the previous three weeks using a 100 mm VAS (6, 284). Neck
circumference, NP and NS were measured and the warm-up performed following the same protocol outlined in Part I Section 4.4.4 for both the start and end of season assessment.

**Peak force assessment.** Once positioned in the testing apparatus, the relaxed weight of the head on the four force transducers was recorded as part of the calibration protocol. To account for the weight of the head or the pressure on the force transducers in a neutral position, these values were subtracted from the maximal values achieved for each direction. Immediately preceding data collection, participants were familiarised with the apparatus and tasks by performing two or three submaximal contractions and then a single unrecorded maximal voluntary contraction (MVC) in each tested direction. A single isometric MVC was then performed for Ext, Flx, LtFlx and RtFlx in a randomly determined order that varied for each participant. Instructions regarding the performance of each MVC were conducted as described in Chapter 4 Part I Section 4.4.4. The maximum force achieved during the 5 s was recorded as the MVC in Newtons (N).

**Submaximal endurance assessment.** Participants performed a single submaximal endurance trial for all four directions following the same testing order as the peak force assessment. Instructions regarding the performance of each submaximal endurance trial and protocol were conducted as described in Chapter 4 Part II Section 4.10.4.

**Endurance trial data processing.** Endurance trials were analysed to determine the area under the force curve (AUC) and the times to fatigue (TTF) for all four directions (Ext, Flx, LtFlx and RtFlx). The AUC was used as an index of cervical muscle fatigue during each endurance trial and was calculated using MATLAB (MathWorks®, Natick, MA) incorporating the trapezium rule method. The MVC peak forces recorded during the start of season assessment were used to calculate the 70% and 90% MVC target forces for the end of season endurance trials. This recording allowed for direct comparisons between the start and end of season assessment periods to determine whether changes in endurance performance had occurred. The description and calculation of %AUC and TTF values is provided in Chapter 4 Part II Section 4.10.4.

**5.3.7 Statistical analyses**

Descriptive statistics (means and SD) were calculated for the anthropometric variables, MVC, %AUC and TTF for each direction (Ext, Flx, LtFlx and RtFlx) and session (start and end of season) for each of the three groups (forwards, backs and controls). For a detailed outline of
the statistical processes used to guide the analysis, refer to Figure 5.2. Previous research examining peak force has highlighted the importance of data normalization between strength measures and anthropometric variables to enable comparisons of strength between individuals (4). For the purpose of this study the term normalization refers to the adjustment of the examined physiological measure (peak force or endurance) to remove the contribution of body size (age, height, weight, neck girth) to the overall variation in the data (4). Pearson’s product-moment correlations were calculated to initially explore the relationship between the peak force and endurance measures to the continuous anthropometric variables: age, weight, height and neck girth (75, 289). To determine whether it was necessary to control for variations in body size among the three groups, each anthropometric variable was assessed using a mixed model ANCOVA to develop predictive models for the entire sample as a whole (4). If none of the anthropometric variables contributed meaningfully to the variance in the models for peak force or endurance, analysis was continued using the raw data. However, if a variable contributed to the variance in the model, a formula was developed to normalize the respective strength and/or endurance measures to account for the variability due to the differences in the anthropometric variable (4). The basis for deriving these normalized values was the strong relationship between anthropometric variables such as body weight and peak force (4, 289).

A 3(group) x 2(time) mixed model ANOVA was then conducted on the raw endurance and the normalized peak force data. Where appropriate, Bonferroni comparisons were used to explore the statistically significant main effects for group and time. For statistically significant interactions, visual inspection of the mean MVC, TTF and the %AUC values at the start and end of season for all four directions were conducted using methods described by Jaccard and Guilamo-Ramos (290). Single degree-of-freedom contrasts (dependent t-tests) were then used to examine if statistically significant changes in the forwards, backs and controls had occurred (290). Statistical significance for the interaction and single degree of freedom contrast were determined using a directional α level of 0.05.

To determine the relative reliability of the device and testing procedures, average and single measure Intra-class Correlation Coefficients (ICC\(_{(3,1)}\)) and 95% confidence intervals (95% CI) were calculated using the MVC values from the start and end of season for each direction. The ICCs were evaluated using the following criteria: poor ICC< 0.50, moderate 0.50 ≤ ICC < 0.70, good 0.70 ≤ ICC < 0.90, and excellent ICC ≥ 0.90 (163).
Absolute reliability was determined using the measurement error associated with a single MVC measurement, calculated as the SEM using the following formula: 
\[ \text{SEM} = SD \times \sqrt{(1 - ICC)} \] (286). The SD value used was the SD for the start and end of season combined and the ICC value was the 2-way random model single measure consistency value. This ICC value was chosen because it is a reflection of the error associated with a measurement collected at a single point in time (286). The %SEM was calculated using the average mean peak force (291). The error associated with multiple measures of maximum strength for each direction was calculated as the minimal detectable change (MDC). The MDC is the smallest amount of change in the MVC scores that can be considered actual change that exceeds error in the measurement. MDC was determined using the following formula: 
\[ \text{MDC} = 1.96 \times \sqrt{2} \times \text{SEM} \] and was calculated to the 95% confidence level (287).

For the current, average and worst NP and NS VAS values, a difference score was calculated between the end and start of the season. If normality violations were present, a log transform was conducted on the difference scores (95, 292). Following the data transformation, a one-way ANOVA was run for each VAS score with a Tukey’s post-hoc comparison to evaluate group differences. If the Levene’s statistic indicated unequal variance between the three groups, a Games-Howell comparison was used. SPSS 19.0 (IBM SPSS Statistics, Somers, N.Y.) was used for all statistical analyses, and the criteria for statistical significance was set at \( \alpha = 0.05 \).
Figure 5.2: A guide outlining the statistical analysis processes used
5.4 Results

5.4.1 Participant characteristics

Fifty-eight participants (25F, 16B, 17CON) were recruited. Due to scheduling conflicts \( n=5 \) and injury \( n=4 \) during the season only 47 participants (21F, 11B, 15CON) completed the end of season assessment. Characteristics for those that completed both testing sessions are reported in Table 5.1. Independent t-tests were used to verify that the anthropometric variables of those that completed both testing sessions were not different from those who did not, no differences were found between the three groups. The one-way ANOVA revealed a statistically significant effect for height, \( F_{(2,55)}=3.29, p=0.04 \), weight, \( F_{(2,55)}=14.44, p<0.01 \), and neck girth, \( F_{(2,55)}=15.63, p<0.01 \), between the three groups. Bonferroni post-hoc analysis \( p=0.05 \) revealed the forwards were taller \((182.92cm)\) than the controls \((178.71cm)\). For both weight and neck girth, the forwards were larger than backs \( p<0.01 \) and the controls \( p<0.01 \).

Table 5.1: Characteristics of the forwards, backs and control groups completing both assessments, measured at the season start \( n=47 \)

<table>
<thead>
<tr>
<th>Measure</th>
<th>Forwards ( n=21 )</th>
<th>Backs ( n=11 )</th>
<th>Controls ( n=15 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>Mean 22.64 SD 2.69</td>
<td>Mean 21.56 SD 2.73</td>
<td>Mean 24.53 SD 5.10</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>182.92* 6.06</td>
<td>180.10 5.47</td>
<td>178.71 4.27</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>103.10* 10.81</td>
<td>80.38** 22.22</td>
<td>83.03 11.88</td>
</tr>
<tr>
<td>Neck girth (cm)</td>
<td>43.49* 2.46</td>
<td>40.00** 2.20</td>
<td>39.89 2.47</td>
</tr>
<tr>
<td>Number of games played over season</td>
<td>13.29 2.78</td>
<td>12.36 3.64</td>
<td>NA NA</td>
</tr>
<tr>
<td>Years of rugby played</td>
<td>13.71 4.53</td>
<td>12.91 4.04</td>
<td>NA NA</td>
</tr>
</tbody>
</table>

* Forwards significantly different than the controls
** Forwards significantly different than the backs

5.4.2 Peak force

5.4.2.1 Normalization

To determine which anthropometric variables were correlated to peak force production, Pearson’s product-moment correlations were conducted (Table 5.2) \( 75 \). Neck girth and weight were the only variables correlated to neck strength. A separate mixed model ANCOVA was then conducted for each of the strength variables using the continuous anthropometric variables as covariates to develop predictive models \( 4 \). The resulting models highlighted neck girth as the only variable that contributed significantly to the variance. The
resulting formulae were used to normalize the respective strength variables to account for the variability due to the differences in neck girth between the three groups. Descriptive statistics (mean and $SD$) for the normalized peak force values for all four directions are presented in Table 5.3.

**Table 5.2**: Pearson’s product-moment correlations for neck muscle peak force and the continuous anthropometric variables measured at the start of the season

<table>
<thead>
<tr>
<th>Characteristic</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ext</td>
<td>Flx</td>
<td>LtFlx</td>
<td>RtFlx</td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>$r$</td>
<td>0.13</td>
<td>0.01</td>
<td>-0.03</td>
</tr>
<tr>
<td></td>
<td>$p$</td>
<td>0.39</td>
<td>0.93</td>
<td>0.83</td>
</tr>
<tr>
<td>Neck girth (cm)</td>
<td>$r$</td>
<td>0.63</td>
<td>0.44</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>$p$</td>
<td>0.01*</td>
<td>0.01*</td>
<td>0.02*</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>$r$</td>
<td>0.07</td>
<td>0.03</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>$p$</td>
<td>0.65</td>
<td>0.83</td>
<td>0.57</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>$r$</td>
<td>0.35</td>
<td>0.30</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>$p$</td>
<td>0.02*</td>
<td>0.04*</td>
<td>0.38</td>
</tr>
</tbody>
</table>

* Denotes a statistically significant correlation ($p < 0.05$)
Table 5.3: Normalized peak force (N) and absolute and relative reliability values for the forwards (F: n= 21), backs (B: n= 11) and controls (CON: n= 15) at the start and end of the season

<table>
<thead>
<tr>
<th>Direction</th>
<th>Group</th>
<th>Start of season</th>
<th>End of season</th>
<th>Δ</th>
<th>ICC(3,1)</th>
<th>95% CI</th>
<th>SEM</th>
<th>% SEM</th>
<th>MDC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extension</td>
<td>F</td>
<td>288.85</td>
<td>113.29</td>
<td>336.07</td>
<td>99.16</td>
<td>47.22*</td>
<td>0.92</td>
<td>0.81-0.97</td>
<td>29.27</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>282.86</td>
<td>59.23</td>
<td>312.61</td>
<td>45.81</td>
<td>29.75*</td>
<td>0.77</td>
<td>0.14-0.94</td>
<td>25.32</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>334.87</td>
<td>52.17</td>
<td>315.16</td>
<td>39.71</td>
<td>-19.71</td>
<td>0.67</td>
<td>0.00-0.89</td>
<td>26.58</td>
</tr>
<tr>
<td>Flexion</td>
<td>F</td>
<td>190.17</td>
<td>133.22</td>
<td>225.44</td>
<td>116.68</td>
<td>35.27*</td>
<td>0.96</td>
<td>0.90-0.98</td>
<td>25.20</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>168.99</td>
<td>30.46</td>
<td>204.13</td>
<td>42.26</td>
<td>35.14*</td>
<td>0.44</td>
<td>-1.08-0.85</td>
<td>27.23</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>190.08</td>
<td>37.00</td>
<td>186.58</td>
<td>37.43</td>
<td>-3.50</td>
<td>0.88</td>
<td>0.64-0.96</td>
<td>12.97</td>
</tr>
<tr>
<td>LtFlx</td>
<td>F</td>
<td>163.65</td>
<td>81.81</td>
<td>222.73</td>
<td>86.98</td>
<td>59.08*</td>
<td>0.91</td>
<td>0.79-0.96</td>
<td>24.63</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>174.04</td>
<td>52.53</td>
<td>220.44</td>
<td>43.06</td>
<td>46.40*</td>
<td>0.84</td>
<td>0.42-0.96</td>
<td>18.91</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>182.77</td>
<td>46.72</td>
<td>198.60</td>
<td>41.12</td>
<td>15.83</td>
<td>0.82</td>
<td>0.47-0.94</td>
<td>18.55</td>
</tr>
<tr>
<td>RtFlx</td>
<td>F</td>
<td>175.42</td>
<td>99.68</td>
<td>222.00</td>
<td>82.36</td>
<td>46.58*</td>
<td>0.85</td>
<td>0.64-0.94</td>
<td>34.67</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>183.92</td>
<td>57.43</td>
<td>216.58</td>
<td>36.71</td>
<td>32.66</td>
<td>0.41</td>
<td>-1.18-0.84</td>
<td>36.04</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>191.31</td>
<td>44.65</td>
<td>185.55</td>
<td>31.62</td>
<td>-5.77</td>
<td>0.79</td>
<td>0.36-0.93</td>
<td>17.61</td>
</tr>
</tbody>
</table>

* Denotes a statistically significant result p< 0.05
5.4.2.2 Normalized peak force

To compare these normalized peak force values for the forwards, backs and controls across the season a 3(group) x 2(time) mixed model ANOVA was conducted for each of the four directions. For all directions, a statistically significant main effect for time and the interaction were observed, indicating varying responses for the three groups over the season (Figure 5.3). However, the main effect for group was not statistically significant, suggesting that when collapsed across time there was no difference in the normalized peak force values between the three groups (Table 5.4). To further explore the statistically significant relationships between the three groups, interaction contrasts were conducted. Visual inspection of the mean values revealed potentially interesting interaction contrasts between the forwards vs controls and the backs vs controls. When the normalized peak force values for the forwards were compared to the controls, the forwards were stronger in all four directions than the controls, over the course of a season. Comparison of the normalized peak force values over the season for the backs vs the controls illustrated that the backs were only stronger for Ext and Flx. When each group was examined independently, the forwards’ neck strength improved for all four directions from the start to the end of the season. This same trend was observed for the backs with the exception of RtFlx. In contrast, the controls’ neck strength remained unchanged over the examined time period.
Figure 5.3: Raw peak force values (N) for the forwards, back and controls at the start and end of the season for the four tested directions
* Denotes a statistically significant result p< 0.05
### Table 5.4: Repeated measures analysis of variance, interaction and the single degree of freedom contrasts time in season (start and end) for the forwards (F: \(n=21\)), backs (B: \(n=11\)) and controls (CON: \(n=15\)) for normalized peak force (N)

<table>
<thead>
<tr>
<th></th>
<th>Main effect</th>
<th>Interaction contrasts</th>
<th>Single degree of freedom contrasts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time (F_{(1, 44)})</td>
<td>Group (F_{(2, 44)})</td>
<td>Interaction effect (t)</td>
</tr>
<tr>
<td>MVC</td>
<td>Ext</td>
<td>6.10 .02*</td>
<td>7.65 .01*</td>
</tr>
<tr>
<td></td>
<td>Flx</td>
<td>12.48 .01*</td>
<td>4.38 .02*</td>
</tr>
<tr>
<td></td>
<td>LtFlx</td>
<td>42.83 .01*</td>
<td>4.96 .01*</td>
</tr>
<tr>
<td></td>
<td>RtFlx</td>
<td>8.65 .01*</td>
<td>4.03 .02*</td>
</tr>
</tbody>
</table>

* Denotes a statistically significant result \(p<0.05\)
5.4.2.3 Peak force absolute and relative reliability

To examine the reliability of the normalized peak force values from the start to the end of the season ICC(3,1), SEM and MDC values were examined. As the peak force response between the three groups over the season varied for each direction the reliability values for the forwards, backs and controls were examined independently.

**Forwards.** The ICC(3,1) measures for Ext, Flx and LtFlx for the forwards were all excellent ranging from 0.91-0.96, while the ICC for RtFlx was good (0.85). When compared to the backs and controls for each direction, the forwards recorded the highest ICC(3,1) values over the 20 week season. Although the results for the single degree-of-freedom contrasts indicated that statistically significant improvements in peak force had been achieved for all four directions in the forwards, none of the improvements reached or exceeded the MDC values. The mean difference from the end to the start of the season was approximately half the value of the MDC for each direction. The MDC values ranged from 68.28-96.11 N and followed a similar pattern to the SEM.

**Backs.** The ICC(3,1) measures for the backs were more variable which could be a function of the small sample size or an indication of greater variability in the peak force measures between individuals over the season. The ICC(3,1) values for Ext (0.77) and LtFlx (0.85) were both good, while Flx and RtFlx were poor (0.41-0.44). The MDC values for the backs ranged from 52.41-99.89 N. When the backs MDC values were compared to the forwards, MDCs for LtFlx and Ext were substantially lower for the backs. Similar to the pattern observed in the forwards statistically significant improvements in peak force were seen for every direction with the exception of RtFlx; however, none of these changes reached the MDC level.

**Controls.** The ICC(3,1) values for the control group were all categorized as good, ranging from 0.79-0.88, with the exception of Ext which was moderate with a value of 0.67. For every direction with the exception of Ext, the control group recorded the smallest SEM values (12.97-18.55 N) indicating less variability in the measure over the 18 week season. The single degree-of-freedom contrast indicated that no changes in strength occurred for this group; therefore, the mean peak force difference between the start and the end of the season was substantially smaller than the MDC values for the
respective directions. When the MDC values were compared to the other groups, the results for Ext (73.69 N) and LtFlx (51.41 N) were similar to the MDC values obtained for the ruby cohort. However, the Flx (35.96 N) and RtFlx (48.81 N) were approximately half of the values recorded for the rugby cohort.

5.4.3 Endurance trials normalization

To determine whether the endurance measures (TTF and %AUC) were correlated to any of the anthropometric variables Pearson’s product-moment correlations were conducted (75). No correlations with age, weight, height or neck girth were observed for %AUC and TTF results for any of the four directions. For %AUC, the Pearson’s correlation values for the sample ranged from $r = -0.12$ to 0.17 for age, $r = -0.24$ to 0.8 for height, $r = 0.01$ to 0.17 for weight, and $r = -0.01$ to 0.09 for neck girth. The TTF $r$-values for age ($r = -0.12$ to 0.14), height ($r = -0.24$ to 0.06), weight ($r = -0.00$ to 0.16) and neck girth ($r = -0.87$ to 0.08) were all statistically non-significant. A mixed model ANCOVA was conducted for the %AUC and TTF values using the continuous anthropometric variables; however, no significant correlations with the endurance results were found. As no correlations were present, normalization of the raw %AUC and TTF was not necessary.

5.4.4 Percent area under the curve (%AUC)

To determine whether the season imposed different levels of stress on the endurance capacity of the cervical musculature for the forwards and backs the AUC for the submaximal endurance trials were analysed. As the 70% and 90% force requirements for the endurance trials were determined using each participant’s MVC, the AUC values were normalized to the individual’s respective MVC for each direction generating a %AUC value. Raw %AUC are presented in Figure 5.4 and Table 5.5. For the Ext direction no changes were observed from the start to the end of the season for the main effect of time, $F_{(1,44)}=0.255$, $p= 0.62$, or the time x group interaction, $F_{(2,44)}=0.15$, $p=0.86$, but a statistically significant effect for group, $F_{(2,44)}=4.13$, $p= 0.02$, was recorded. Further post-hoc examination revealed that forwards ($p= 0.04$) and backs ($p= 0.05$) Ext %AUC values were larger than the controls. The single degree of freedom contrasts for all three groups were statistically non-significant, indicating no change in endurance capacity from the start to the end of the season for any of the
groups. Visual examination of the mean values for the three groups revealed potential interaction between the forwards and the controls and the backs and controls. Although the absolute values showed a greater decline in %AUC for the forwards (-4.52 %AUC) when compared to the controls (-0.37 %AUC), there was no statistically significant difference between the two groups, \( t_{(34)} = 0.35, p = 0.73 \). A similar result was found for the absolute decrease over the season between the backs (-0.77 %AUC) and the controls (-0.37 %AUC), \( t_{(24)} = -0.84, p = 0.41 \).

As illustrated in Table 5.6 no differences were observed between the three groups from the start to the end of the season for the %AUC values for Flx, LtFlx or RtFlx (\( p \)-values ranged from 0.24-0.99). Given the large standard deviation in the %AUC values, not surprisingly there were no statistically significant changes (\( p \)-values ranged from 0.25-0.95) for any of the three groups when examined independently from the start to the end of the season (Table 5.6).

Figure 5.4: Percent area under the force curve for the submaximal endurance trial for the forwards, backs and controls for the four measured directions, where no significant differences were observed over time or between the three groups.
Table 5.5: Percent area under the force curve raw values (%AUC) for the endurance trial and absolute and relative reliability values for the forwards (F: n = 21), backs (B: n = 11) and controls (CON: n = 15) at the start and end of the season

<table>
<thead>
<tr>
<th>Direction</th>
<th>Group</th>
<th>Start of season</th>
<th>End of season</th>
<th>Δ</th>
<th>ICC_{3,1}</th>
<th>95% CI</th>
<th>SEM</th>
<th>MDC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extension</td>
<td>F</td>
<td>71.55 58.55</td>
<td>67.04 53.85</td>
<td>-4.52</td>
<td>0.94</td>
<td>0.84-0.98</td>
<td>17.16</td>
<td>47.56</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>74.09 57.80</td>
<td>73.33 65.52</td>
<td>-0.77</td>
<td>0.76</td>
<td>0.11-0.94</td>
<td>12.19</td>
<td>33.78</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>28.06 18.65</td>
<td>27.69 22.71</td>
<td>-0.37</td>
<td>0.66</td>
<td>-0.21-0.88</td>
<td>12.11</td>
<td>33.56</td>
</tr>
<tr>
<td>Flexion</td>
<td>F</td>
<td>47.75 49.81</td>
<td>56.93 45.51</td>
<td>9.18</td>
<td>0.46</td>
<td>-0.36-0.79</td>
<td>11.84</td>
<td>32.82</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>56.97 56.98</td>
<td>64.68 55.22</td>
<td>7.72</td>
<td>0.85</td>
<td>0.46-0.96</td>
<td>21.38</td>
<td>59.27</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>52.63 42.24</td>
<td>59.74 52.97</td>
<td>7.11</td>
<td>0.93</td>
<td>0.80-0.98</td>
<td>12.36</td>
<td>34.27</td>
</tr>
<tr>
<td>LtFlx</td>
<td>F</td>
<td>98.40 60.53</td>
<td>94.82 66.63</td>
<td>-3.59</td>
<td>0.80</td>
<td>0.50-0.92</td>
<td>28.43</td>
<td>78.80</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>82.17 53.55</td>
<td>83.34 60.25</td>
<td>1.18</td>
<td>0.96</td>
<td>0.85-0.99</td>
<td>11.42</td>
<td>31.66</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>85.49 60.74</td>
<td>79.37 64.82</td>
<td>-6.12</td>
<td>0.85</td>
<td>0.55-0.95</td>
<td>24.46</td>
<td>67.80</td>
</tr>
<tr>
<td>RtFlx</td>
<td>F</td>
<td>87.60 73.61</td>
<td>87.67 76.18</td>
<td>0.07</td>
<td>0.91</td>
<td>0.76-0.96</td>
<td>22.87</td>
<td>63.39</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>77.80 65.12</td>
<td>65.02 66.57</td>
<td>-12.77</td>
<td>0.73</td>
<td>0.00-0.93</td>
<td>34.12</td>
<td>94.59</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>82.94 64.85</td>
<td>97.32 56.21</td>
<td>14.38</td>
<td>0.85</td>
<td>0.48-0.94</td>
<td>23.58</td>
<td>65.37</td>
</tr>
</tbody>
</table>
### Table 5.6: Repeated measures analysis of variance, interaction contrasts and the single degree of freedom contrasts for the percent area under the curve values (%AUC), conducted at the start and end of the season for the forwards (F: \( n= 21 \)), backs (B: \( n= 11 \)) and controls (CON: \( n= 15 \))

<table>
<thead>
<tr>
<th></th>
<th>Main effect</th>
<th>Interaction contrasts</th>
<th>Single degree of freedom contrasts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time</td>
<td>Group</td>
<td>F vs B</td>
</tr>
<tr>
<td></td>
<td>( F_{(1, 44)} ) ( p )</td>
<td>( F_{(2, 44)} ) ( p )</td>
<td>( t_{(30)} ) ( p )</td>
</tr>
<tr>
<td>MVC Ext</td>
<td>0.26 .62</td>
<td>4.13 .02*</td>
<td>0.15 .86</td>
</tr>
<tr>
<td>Flx</td>
<td>1.41 .24</td>
<td>0.13 .88</td>
<td>0.01 .99</td>
</tr>
<tr>
<td>LtFlx</td>
<td>0.18 .68</td>
<td>0.34 .72</td>
<td>0.09 .92</td>
</tr>
<tr>
<td>RtFlx</td>
<td>0.01 .94</td>
<td>0.31 .73</td>
<td>0.99 .38</td>
</tr>
</tbody>
</table>

* Denotes a statistically significant result \( p < 0.05 \)
5.4.4.1 Percent area under the force curve absolute and relative reliability

As a significant group effect was observed for Ext and the mean and SD values appear to varying between the three groups the reliability values for each group were analysed separately (Table 5.5).

Forwards. The ICC\(_{(3,1)}\) measures for Ext and RtFlx for the forwards were all excellent ranging from 0.91-0.94, while LtFlx tested good (0.80), and Flx was poor (0.46). When compared to the backs and controls, the forwards recorded the highest ICC\(_{(3,1)}\) values over the 20 week season for Ext and RtFlx. The values for the SEM for the four directions ranged from 11.84-28.43 %AUC. The largest value was achieved for LtFlx indicating more variability in this measure while the smallest was isolated for Flx. The MDC values ranged from 32.82-78.80 %AUC and followed a similar pattern to the SEM.

Backs. The ICC\(_{(3,1)}\) measures for the backs were the most consistent of the three groups for the %AUC values. The ICC\(_{(3,1)}\) values for LtFlx (0.96) was excellent, while Ext, Flx, and RtFlx all achieved a score ranking them as good (0.73-0.85). The SEM values for the backs ranged from 11.42-34.12 %AUC. When the SEM values for the backs were compared to the forwards, SEMs for Ext and LtFlx were substantially lower for the backs. The opposite pattern was observed for the SEMs for Flx and RtFlx. The MDC demonstrated a similar pattern and ranged from 31.66-94.59 %AUC, indicating large improvements are needed for these variables to obtain a clinically meaningful improvement.

Controls. The ICC\(_{(3,1)}\) values for the control group were categorized as the following: moderate for Ext (0.66), good for LtFlx (0.85) and RtFlx (0.85), and excellent for Flx (0.93). The SEMs were approximately equivalent for Ext and Flx, 12.11 and 12.36 %AUC respectively. This same trend was observed for LtFlx (24.46 %AUC) and RtFlx (23.58 %AUC). Although slightly more variable, the same pattern seen in the controls for the SEM was seen in the forwards. The MDC values followed a similar trend to the SEM and ranged from 33.56-67.80 %AUC.
5.4.5 Time to fatigue

To compare the lengths of submaximal endurance trials at the start and end of the season the TTF for each direction were compared for the three groups, see Figure 5.5. For each direction a 3(group) x 2(time) mixed model ANOVA for the TTF variables was conducted. The Ext direction revealed no effect for time, $F_{(1,44)}= 0.64$, $p= 0.43$, and the interaction of time by group, $F_{(2,44)}=0.22$, $p= 0.80$, but a statistically significant effect for group, $F_{(2,44)}= 4.08$, $p= 0.02$. Further post-hoc examination of the significant main effect for group revealed that the forwards ($p= 0.05$) and the backs ($p= 0.05$) were able to sustain the Ext submaximal contraction for significantly longer periods of time than the controls. No differences were found between the forwards and backs. The single degree of freedom contrasts for all three groups were statistically non-significant, indicating no change in TTF from the start to the end of the season. Visual examination of the mean values for the three groups revealed potential interaction contrasts of interest between the forwards and the controls and the backs and controls. Despite the fact that the forwards demonstrated a larger decrease in the TTF for Ext (-4.29 s) when compared to the controls (0.06 s), the difference between the two groups was not statistically significant, $t_{(34)}= 0.36$, $p= 0.72$. A similar result was isolated for the interaction contrast between the backs (-2.75 s) and the controls (0.06 s), $t_{(24)}= -0.24$, $p= 0.82$.

No differences were observed between the three groups from the start to the end of the season for the TTF values for Flx, LtFlx or RtFlx see Table 5.7 ($p$ values ranged from 0.26-0.99). Given the large standard deviation in the TTF values, there were no statistically significant changes for any of the three groups when examined independently from the start to the end of the season, where $p$ values ranged from 0.26-0.99 (Table 5.8).
Figure 5.5: Time to fatigue (s) for the submaximal endurance trial for the forwards, backs and controls at the start and end of the season for the four measured directions, where no significant differences were observed over time or between the three groups.
Table 5.7: Time to fatigue (s) and absolute and relative reliability values for the forwards (F: *n*= 21), backs (B: *n*= 11) and controls (CON: *n*= 15) at the start and end of the season

| Direction | Group | Start of season | End of season | | | | | | | |
|-----------|-------|----------------|---------------|-----|-------|-------|-------|-------|-------|
|           |       | Mean           | SD            | Mean | SD    | Δ     | ICC<sub>(3,1)</sub> | 95% CI | SEM | MDC |
| Extension | F     | 61.30          | 46.21         | 57.01 | 42.89 | -4.29 | 0.91 | 0.76-0.96 | 13.66 | 37.87 |
|           | B     | 65.56          | 49.62         | 62.81 | 52.43 | -2.75 | 0.97 | 0.90-0.99 | 8.23  | 22.82 |
|           | CON   | 26.53          | 15.55         | 26.59 | 18.20 | 0.06  | 0.67 | 0.3-0.89  | 9.62  | 26.68 |
| Flexion   | F     | 41.68          | 39.63         | 48.61 | 35.90 | 6.93  | 0.47 | -0.34-0.79 | 27.48 | 76.16 |
|           | B     | 48.19          | 44.50         | 54.21 | 43.19 | 6.02  | 0.85 | 0.44-0.96 | 16.95 | 47.00 |
|           | CON   | 45.57          | 34.54         | 50.93 | 42.24 | 5.37  | 0.94 | 0.82-0.98 | 9.49  | 26.31 |
| LtFlx     | F     | 82.12          | 47.80         | 78.81 | 53.10 | -3.31 | 0.80 | 0.50-0.92 | 22.46 | 62.25 |
|           | B     | 69.36          | 42.71         | 70.88 | 47.94 | 1.52  | 0.96 | 0.84-0.99 | 9.40  | 26.06 |
|           | CON   | 72.91          | 48.23         | 67.11 | 51.14 | -5.81 | 0.84 | 0.52-0.95 | 19.84 | 55.00 |
| RtFlx     | F     | 73.53          | 57.57         | 73.35 | 60.66 | -0.18 | 0.91 | 0.76-0.96 | 18.13 | 50.24 |
|           | B     | 65.17          | 51.26         | 65.09 | 54.76 | -0.08 | 0.90 | 0.62-0.97 | 16.94 | 46.96 |
|           | CON   | 70.43          | 51.40         | 81.85 | 44.81 | 11.42 | 0.82 | 0.47-0.94 | 20.34 | 56.37 |
Table 5.8: The time to fatigue results for the repeat measures analysis of variance, interaction and the single degree of freedom contrasts conducted at the start and the end of the season for the forwards (F: n = 21), backs (B: n = 11) and controls (CON: n = 15)

<table>
<thead>
<tr>
<th>Main effect</th>
<th>Interaction effects</th>
<th>Single degree of freedom contrasts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Group</td>
<td>Interaction effect</td>
</tr>
<tr>
<td>F (1, 44) p</td>
<td>F (2, 44) p</td>
<td>F vs B (2, 44) p</td>
</tr>
<tr>
<td>MVC Ext 0.64 .43</td>
<td>MVC Ext 0.22 .80</td>
<td>-0.24 .82</td>
</tr>
<tr>
<td>MVC Ext 4.08 .26</td>
<td>MVC Ext 0.36 .72</td>
<td>~ ~</td>
</tr>
<tr>
<td>MVC Ext 0.01 .99</td>
<td>MVC Ext 0.01 .99</td>
<td>~ ~</td>
</tr>
<tr>
<td>MVC Ext 0.14 .87</td>
<td>MVC Ext 0.14 .87</td>
<td>~ ~</td>
</tr>
<tr>
<td>MVC Ext 0.55 .58</td>
<td>MVC Ext 0.55 .58</td>
<td>~ ~</td>
</tr>
<tr>
<td>MVC Ext 0.49 .49</td>
<td>MVC Ext 0.49 .49</td>
<td>~ ~</td>
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<tr>
<td>MVC Ext 0.15 .86</td>
<td>MVC Ext 0.15 .86</td>
<td>~ ~</td>
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<tr>
<td>MVC Ext 0.55 .58</td>
<td>MVC Ext 0.55 .58</td>
<td>~ ~</td>
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<tr>
<td>MVC Ext 0.49 .49</td>
<td>MVC Ext 0.49 .49</td>
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<tr>
<td>MVC Ext 0.15 .86</td>
<td>MVC Ext 0.15 .86</td>
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<td>MVC Ext 0.49 .49</td>
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<tr>
<td>MVC Ext 0.55 .58</td>
<td>MVC Ext 0.55 .58</td>
<td>~ ~</td>
</tr>
</tbody>
</table>

* Denotes a statistically significant result p < 0.05
5.4.5.1 Time to fatigue absolute and relative reliability

Similar to the pattern observed in the %AUC for Ext, the Ext TTF values for the forwards and backs were higher than those observed for the controls. In addition to this groups difference, the SD for Ext and Flx at the start and end of the season varied for the three groups. Given these findings, the reliability values in the forwards, backs and controls were examined separately (Table 5.7).

**Forwards.** The ICC\(_{(3,1)}\) measures for Ext and RtFlx in the forwards were excellent, both yielding values of 0.91, while LtFlx ranked good (0.80), and Flx was poor (0.47). The values for the SEM for the four directions ranged from 13.66-27.48 s. The largest value was achieved for Flx indicating more variability in this measure, while the smallest was isolated for Ext. The MDC values ranged from 37.87-76.16 s and followed a similar pattern to the SEM.

**Backs.** The ICC\(_{(3,1)}\) measures for the backs were the most consistent of the three groups for the TTF values. The ICC\(_{(3,1)}\) values for Ext, LtFlx and RtFlx were all excellent ranging from (0.90-0.97), while Flx ranked good (0.85). The SEM values for the backs ranged from 8.23-16.95 s. The SEMs for Flx and LtFlx for the backs were approximately half the size of the values obtained for the forwards. While the SEM values for Ext and RtFlx for the backs were smaller but closer in proximity to the values recorded for the forwards. The MDC demonstrated a similar pattern and ranged from 22.82-47.00 s, indicating moderate improvements are needed for these variables to obtain a clinically meaningful improvement.

**Controls.** The ICC\(_{(3,1)}\) values for the control group were categorized as the following: moderate for Ext (0.67), good for LtFlx (0.84) and RtFlx (0.82), and excellent for Flx (0.94). The SEMs were approximately equivalent for Ext and Flx, 9.62 s and 9.49 s respectively. This same trend was observed for LtFlx (19.84 s) and RtFlx (20.34 s). The MDC values followed a similar trend to the SEM and ranged from 26.31-56.37 s.

5.4.6 Self-reported neck pain VAS scores

One of the purposes of this study was to examine the changes that occurred in self-reported NP over a season for the three respective groups as shown diagrammatically in Figure 5.6 and Table 5.9. To determine whether these increases in NP for the forwards
and the backs were statistically significant when compared to the NP scores for the controls, a one-way ANOVA was conducted on the log transformed difference scores. The Levene’s statistic was significant for the current NP scores, indicating unequal variance between the three groups. The Games-Howell post-hoc analysis revealed no difference in pain scores between the forwards and backs ($p = 0.79$) and the backs and the controls ($p = 0.17$); however, the increase in NP observed for the forwards was greater when compared to the controls ($p = 0.05$). In contrast to these findings, no statistically significant differences were isolated between the three groups for average or worst NP, which is likely due to the large variation in self-reported NP for these measures.

![Figure 5.6: Raw current, average and worst neck pain visual analogue scores (mm) over the season in the forwards, backs and controls](image)

* Denotes statistical significance $p < 0.05$

To further explore these changes single degree of freedom contrast for the forwards were conducted and indicated that NP increased for current, $t_{(20)} = 2.94$, $p = 0.01$, average, $t_{(20)} = 2.28$, $p = 0.03$, and worst, $t_{(20)} = 2.21$, $p = 0.04$, over the season. For the backs, statistically significant increases in NP were recorded for current, $t_{(10)} = 2.49$, $p = 0.03$, and worst, $t_{(10)} = 2.44$, $p = 0.04$, while average NP remained unchanged, $t_{(20)} = 1.93$, $p = 0.08$. In contrast, the NP scores for the control group remained unchanged over the examined time period for all three VAS scales (current: $t_{(14)} = 1.35$, $p = 0.20$; average: $t_{(14)} = 1.10$, $p = 0.29$; worst: $t_{(14)} = 1.70$, $p = 0.11$).
Table 5.9: Current, average and worst self-reported neck pain (NP) visual analogue scores (mm) over the season in the forwards (F: $n=21$), backs (B: $n=11$) and controls (CON: $n=15$)

<table>
<thead>
<tr>
<th>Group</th>
<th>Current NP</th>
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<td>13.01*</td>
<td>14.00</td>
<td>16.28</td>
<td>25.76</td>
<td>23.84</td>
<td>11.76*</td>
<td>27.90</td>
<td>27.93</td>
<td>37.45</td>
<td>31.04</td>
<td>9.55*</td>
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<td>5.87</td>
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* Denotes statistical significance $p<0.05$
5.4.7 Self-reported neck stiffness VAS scores

The start and end of season values for current, average and worst NS VAS scores over the past three weeks are illustrated in Figure 5.7 and presented in Table 5.10. To examine the changes in NS over the season in the three groups, a one-way ANOVA was conducted on the log transformed difference scores. For current NS, the main effect for group was statistically significant, \( F(2,44) = 3.70, p = 0.03 \). Post-hoc analysis revealed no change between the forwards and the controls \( (p = 0.71) \) and between the forwards and the backs \( (p = 0.23) \). When the observed increase in current NS scores for the backs was compared to the controls, it was statistically significant \( (p = 0.03) \). The average NS main effect for group was not statistically significant, \( F(2,44) = 2.83, p = 0.07 \).

The opposite was seen for the worst NS scores with a statistically significant main effect for group, \( F(2,44) = 3.43, p = 0.04 \), with no differences observed for the forward vs backs or the forwards vs the controls. As seen with the current NS, post-hoc analysis the backs difference score was significantly larger when compared to the controls, \( p = 0.04 \).

In contrast to the NP scores, the forwards’ NS scores were unchanged (current: \( t(20) = 1.53, p = 0.14 \); average: \( t(20) = 1.49, p = 0.15 \); worst: \( t(20) = 1.50, p = 0.15 \)) over the season while the backs’ scores increased for all three measured NS scales (current: \( t(10) = 2.82, p = 0.02 \); average: \( t(10) = 2.97, p = 0.01 \); worst: \( t(10) = 3.32, p = 0.01 \)). Consistent with the NP score, NS for the control group remained unchanged for current, \( t(14) = 0.65, p = 0.53 \), average, \( t(14) = 0.98, p = 0.34 \), and worst, \( t(14) = 1.62, p = 0.13 \) (Table 5.10).
Figure 5.7: Current, average and worst neck stiffness visual analogue scores (mm) over the season in the forwards, backs and controls
* Denotes statistical significance $p < 0.05$
Table 5.10: Current, average and worst self-reported neck stiffness visual analogue scores (mm) over the season in the forwards (F: n= 21), backs (B: n= 11) and controls (CON: n= 15)

| Group    | Current NS | | | | Average NS | | | | Worst NS | | |
|----------|------------|-----------|-----------|-----------|----------------|-----------|-----------|----------------|-----------|-----------|
|          | Start of season | Mean | SD | End of season | Mean | SD | Start of Season | Mean | SD | End of Season | Mean | SD | Start of season | Mean | SD | End of season | Mean | SD | Δ | Mean | SD | Δ |
| Forwards | 20.26 | 21.39 | 30.57 | 27.63 | 10.31 | 21.80 | 20.58 | 31.48 | 27.18 | 9.68 | 35.84 | 26.16 | 44.93 | 32.21 | 9.09 |
| Controls | 10.35 | 13.61 | 12.77 | 14.27 | 2.41 | 10.35 | 14.27 | 13.20 | 15.26 | 2.85 | 15.91 | 16.62 | 18.13 | 15.15 | 2.22 |

* Denotes statistical significance $p< 0.05$
5.5 Discussion

The primary purpose of this study was to monitor the effect of a competitive season on neck muscular strength and endurance, and NP and NS in a cohort of amateur rugby forwards and backs relative to a healthy control group. Participation in a season of rugby resulted in statistically significant improvement in neck strength for all measured directions for the forwards and backs with the exception of RtFlx for the backs. In contrast neck strength in the controls remained unchanged over the same period. Although there is no supporting evidence, many authors suggest that neck strength improvements may offer a protective effect that could minimize or prevent injuries to this region (27, 54, 56, 57). However, in the present study, observed improvements in peak force were paralleled by increases in self-reported NP for both forwards and backs. Surprisingly, forwards reported no seasonal change in NS, while backs reported increases in NS.

This study is the first longitudinal assessment of neck strength and endurance over a competitive season in a sample of rugby players. Previous work examining neck strength in rugby has been limited to single observational studies (74, 76) or the assessment of neck strength over a 5-week period in response to the application of a neck specific intervention in a professional Super 15 team (73). In order to determine whether neck strength and/or endurance modulates the frequency or severity of neck and head injuries in rugby, it is essential to understand the influence of a competitive season on these parameters. To date only active range of motion (ROM) of the cervical spine has been examined over a competitive rugby season (50).

5.5.1 Effects of body mass and neck circumference

In this study forwards were heavier and had larger necks circumferences than the backs and controls. Similar findings for weight have been reported by Lark et al. (48), but the authors did not measure neck circumference. In the current study, both body mass and neck circumference were positively correlated to peak force. Similar results have been documented in weightlifters and wrestlers where positive correlations ($r= 0.73-0.76$) were observed between the cross-sectional area of the cervical semispinalis capitis muscle and body mass (293). In addition, positive correlations between Ext MVC and cervical extensor cross-sectional area have also been reported elsewhere (293-295).
When the correlations were explored further using a mixed model ANCOVA the results revealed that only neck circumference contributed to the variance in peak force measures. In contrast to these findings, neck extensor strength in male adolescent rugby players was positively correlated with age, height, and weight of the participant but not neck circumference (75). This discrepancy could be attributed to the different age ranges of the two studies or methods of strength assessment.

In the current study, the forwards recorded the largest neck circumference values. Visual examination of the raw peak force values between the forwards and backs illustrates a pattern of superior neck strength for the forwards (Figure 5.3). This strength difference may reflect the loads placed on the necks of these players during contact play such as scrummaging and mauling. When asked during the end of season assessment none of the forwards reported engaging in any neck specific exercises outside of playing and/or training for rugby that would impact these results. Similar patterns in neck anthropology and strength were also reported by Tsuyama et al. (293) who compared cervical extension strength in wrestlers and judo athletes. They reported that the cross-sectional area of the cervical extensors and Ext peak force values were greater for wrestlers when compared to judo athletes, which likely reflects the greater demand placed on wrestlers’ necks during participation in that sport than in judo.

To conduct a valid comparison of neck strength of the groups in this study normalization of the peak force was necessary due to body mass and neck circumference differences between groups. Normalization enables modification of force variables to control for individual size variations (4). The examined models indicated that using neck circumference to scale peak force was the most effective anthropometric normalization (4). In contrast, the anthropometric variables did not account for the variability in endurance performance. Given these findings, data normalization was conducted for all four directions for the peak force but not for the endurance variables. In previous research peak neck force has been normalized to participants’ body mass index (BMI); however, no information was provided regarding the method of normalization (166). While other research examining neck strength in professional rugby players has normalized peak torque to body weight using ratio calculations (76), which has the capacity to introduce systematic errors into the results (4).
5.5.2 Peak force

For the current study forwards were stronger than the backs and the controls in all four directions. These findings are consistent with those reported by Oliver et al. (76) in which forwards tested stronger than backs. In contrast, at the academy level forwards’ Ext strength (637.10 N) was greater than the backs’ (537.87 N), but no differences for Flx, LtFlx or RtFlx were recorded between the two groups of players (74).

The normalized peak force improvements for the forwards observed over the season (Ext 16.35%, Flx 18.55%, LtFlx 36.10% and RtFlx 26.55%) suggest that exposure to rugby practice and match play provided sufficient stimulus to improve neck strength measures. A similar trend was observed for the backs with the exception of RtFlx (Ext=10.52%; Flx= 20.79%; and LtFlx 26.66%). Neck strength training has been highlighted as essential for those involved in scrummaging, with a particular emphasis for front row players based on the neck loading during scrummaging (27, 52, 76, 151).

It could be suggested that forwards are more likely to be exposed to activities in a training environment that target the neck musculature. However, the peak force improvements observed in the current study for both the forwards and backs suggests exposure to a common stimulus in matches or training.

To determine whether these observed improvements can be attributed to participation in rugby or if they were a learned effect due to repeated testing, it was essential to compare the rugby cohort to a control population. When the improvements observed for each direction in the forwards over the season were compared to the changes seen in the control group, the improvements remained. A similar pattern was observed for Ext and Flx in the backs when compared to the controls; however, this was not true for LtFlx or RtFlx. It is important to note that the interaction contrast for the backs vs the controls for LtFlx (p= 0.06) and RtFlx (p= 0.07) approached statistical significance. These findings could suggest that participation in contact events such as tackling, collisions and rucks which backs would also engage in during a match or training stimulates strength adaptations in the cervical flexors and extensors, but not in the lateral cervical flexors. Forwards who would also participate in these same phases of play also achieved improvements in Ext and Flx. However, forwards are also involved in scrummaging which may explain the observed improvements in LtFlx and RtFlx.
In the literature, the current recommendation is to assess the absolute reliability of a measurement tool using SEM and MDC (58, 291, 296). SEM is used to determine the amount of variation or spread in the measurement for a test. The upper and lower boundaries of the MDC are used as clinometric benchmarks to determine whether an improvement or deterioration in performance has occurred (58). Comparison of the absolute reliability measures for the three groups across the four measured directions revealed that SEM and MDC were consistent for Ext and LtFlx. However, for Flx and RtFlx, the control group’s SEM and MDC values were approximately half the values observed for the forwards and backs. A possible explanation for this phenomenon was the occurrence of loading events (e.g. tackling, collisions or scrummaging) during the season which could potentially lead to injury. The presence of injury could impair performance during the end of season assessment, thus contributing to the variability in Flx and RtFlx.

The vertebral column is composed of four curvatures which generates an S or sinusoid shape. These curvatures function to increase the resilience and flexibility of the spine allowing it to behave as a spring rather than a rigid rod (116). Any deviations in the sinusoidal curvature from improper posture as seen during head forward flexion or lateral deviation of the head during contact phases of play will place additional strain upon the spine (130, 297). At the start of season, 90% of the forwards and backs indicated that when making a tackle their preferred tackle shoulder was the right side (the one they lead with in a tackle). Repeated loading of the right shoulder and neck during a tackle for these players could have resulted in cumulative microtrauma in this region of the spine. It is hypothesized that microtrauma occurs after prolonged and repeated exposure of the spine to these mechanical stressors (297) which given the length of the season (20wk) and the frequency of collisions during a match is likely (100). This accumulation of microtrauma over time may eventually lead to the development of macrotrauma, which has the potential to lead to the occurrence of dysfunction and pain (297) and impairment in force production for Flx and RtFlx for these individuals. This speculation may further explain the large SEM and MDC values observed for the forwards and backs in the current study.

Test re-test isometric neck strength has previously been assessed in a sample of academy level rugby players (F: 16 and B: 9) using a handheld dynamometer. The
authors reported combined MDC values for the forwards and backs that were significantly larger for Ext (111.74 N) and LtFlx (112.46 N) than the combined values for the current study’s Ext (75.66 N) and LtFlx (60.34 N) values (74). The opposite pattern was observed for Flx with Geary et al. (74) reporting a MDC value of 51.26 N compared to the current study’s 72.66 N. The RtFlx MDC scores were similar, ranging from 96.11-109.81 N (74). These differences could be explained by the method of assessment used in each of these studies. The handheld dynamometer measurement technique requires fixation by an examiner compared to the fixed frame dynamometer used in the current study where the force transducers are anchored to the actual device (58, 169, 170).

Assessment of academy level rugby players with a handheld dynamometer recorded peak force values for forwards as: Ext 637.10 N, Flx 357.16 N, LtFlx 581.19 N, and RtFlx 576.49 N (74). In comparison, Naish et al. (73) examined cervical peak force values in professional rugby players using a fixed frame dynamometer in a seated position and recorded peak force values of Ext 367.7 N, Flx 277.6 N, LtFlx 363.2 N and RtFlx 376.4 N. The strength values reported by Naish et al. (73) were not grouped by position so no comparison can be made between the forwards and backs. As illustrated previously, the peak force values obtained in amateur players using the handheld dynamometer are substantially higher than those obtained in professional players using a fixed frame dynamometer in the same tested position. This magnitude of difference is unlikely as the expectation is that professional players would produce larger peak force values compared to amateur players. Isometric assessment using a fixed frame dynamometer is often used as a reference standard to compare other instruments that assess muscle strength (169, 170). In a recent review comparing isokinetic to handheld dynamometry, the authors reported, in general, moderate to good reliability and validity when comparing these two devices (169). However, comparison of the raw peak force values obtained for the forwards in the current study (Ext: 326.69 N, Flx 238.86 N, LtFlx 195.05 N, and RtFlx 221.56 N) are closer in range to those achieved by professional players using the fixed frame dynamometer (73). As expected, the values obtained for the amateur forwards in the current study are lower than those observed at the professional level, particularly for LtFlx and RtFlx (73).
Over the season the forwards achieved increases in peak force in all four directions. However, others would suggest it may be more relevant to analyse improvements using MDC values (58, 296). For the current cohort of forwards, the improvements recorded for each direction were approximately half the size of their respective MDC values, with the exception of LtFlx. For the backs, similar results were observed for improvements in Ext and Flx. The improvement achieved for the forwards and the backs for LtFlx came close to approximating an improvement as determined by the MDC, likely due to the fact that the largest improvements in peak force were recorded for this direction. These findings then raise the question are these improvements observed for the players sufficient to offer some sort of protective effect against injury.

Research examining impulsive loading of the neck has proposed that improvements in neck strength, in particular from the SCM and the upper trapezius, may enhance head and neck dynamic stabilization (90, 91, 130, 157). For the current study, the forwards and backs improved their peak Ext forces by 16.3% and 10.5% respectively, while the controls decreased by 5.9%. While statistically significant, these changes did not reach the level where they could be classified as improvements as determined by the MDC (%MDC values for Ext F: 28.0%, B: 24.8% and CON: 22.0%). Although the use of MDC values have been suggested as a statistical proxy to indicate clinical or functional improvements (58), their use is often debated (298-300). The improvement in Ext peak force of 10 to 16% observed over the course of the season in the current study may contribute to enhanced stabilization of the head-neck segment. Previous neck injury surveillance data conducted with similar level players has reported an increased injury frequency during the first 5 weeks of competition (87). Thus as the season progresses rugby training provides a training stimulus for the neck musculature resulting in improved strength, which in turn, may enhance dynamic stabilization leading to reduced injury frequency. As the sample size recruited was insufficient to observe enough neck injuries for statistical analysis, the current study did not assess neck injury frequency in conjunction with neck strength measures, and are therefore unable to determine causation.

5.5.3 Submaximal endurance measures

Research examining injury surveillance data in professional rugby players has reported a trend towards increased frequency of cervical injuries as the match and the season...
progresses (30). Although not formally examined, cervical musculature fatigue may be a risk factor for the occurrence of neck injuries (59, 164). Given the potential link between cervical musculature fatigue and injury, assessment of cervical muscular fatigue is important. However, analysis of the results from the current study revealed a large amount of variability for the %AUC and TTF scores over the season. Variability impairs the ability to observe statistically significant findings which may explain the lack of significant differences between the groups. Future research with a larger cohort of rugby players would permit further positional grouping of players, for example grouping forwards into front row, lock and loose forward groups, which may reduce the inter-individual variability. However, the greater Ext TTF and %AUC values for the forwards and backs compared to the control group suggests that rugby participations imposes a metabolic stress on the cervical extensors, resulting in submaximal endurance adaptation in this region of the spine.

No changes in submaximal endurance measures were recorded for any of the three groups from the start to the end of the season for the four measured directions. As cervical musculature endurance has not been examined previously in collision based athletes, comparison to other results is not possible. For the control population in this study, the %AUC for Ext (33.56 %AUC) and Flx (34.27 %AUC) was less than a previously conducted test-re-test study using the same device Ext (95.09 %AUC) and Flx (116.13 %AUC) (Chapter 4 Part II). However, this study normalized the %AUC values to neck girth and included female participants which may explain the discrepancy in the results. In contrast to the % AUC, the TTF results were approximately equivalent for both Ext (current study: 26.68 s, previous study: 23.78 s) and Flx (current: 26.31 s, previous: 34.73 s) as discussed in Chapter 4. A similar result has been presented in a recent study using the same resistance load (70% MVC) to assess endurance capacity of the cervical musculature in helicopter aircrew (71). Although the aforementioned study employed a sustained submaximal load and the current study used an impulsive load, their control group’s TTF values pre- and post-intervention were similar for Ext and LtFlx. While the Flx values (30.04 s to 39.72 s) for the helicopter pilots were slightly lower and the RtFlx values (55.43 s to 39.47 s) substantially lower than those seen in the current study (71).
5.5.4 Neck pain

Schneiders et al. (87) collected injury surveillance data on 271 premier grade rugby union players (the same level of play of the current rugby cohort) over a 20 week season. The season was grouped into five week quarters and the authors reported that injury frequency was highest in the first quarter (71/1000 player match hours), decreased during the second quarter and levelled out for the second half of the competition (42/1000 player match hours) (87). Combined head and neck trauma accounted for 35% of all injuries; however, the specific frequency of head and neck injuries was not reported (87). Assuming that head and neck injuries for this population followed a similar trend, and that the neck strength response observed in the current cohort is representative of the typical pattern observed at an amateur level, we can speculate that increased neck strength observed at this level over a competitive season may result in a decreased frequency of neck injuries. As injury surveillance data were not collected in the current study, this is only speculation but warrants further research to explore this potential relationship.

Over a four week period, NP in amateur rugby players had a reported prevalence of 83% in forwards and 41% in backs (44), which is higher than the 10-20% reported in the general population (134). A longitudinal examination of NP over a season has not been conducted in collision based sports previously. The current study observed increases in self-reported NP for the forwards ranging from 10 to 13 mm for all measured values. This same pattern was found for the backs (23 to 25 mm), with the exception of average NP which remained unchanged. In contrast, the controls NP scores remained unchanged over the examined time period. When these changes were compared between groups, the only statistically significant result was isolated for the forwards and the controls for current NP. This finding is not unexpected as previous research has identified the loose head prop and the hooker as players most at risk of neck injuries (27, 30, 52).

The observed increases in NP for the forwards and backs in conjunction with the reported increases in NS for the backs in the current study appear to conflict with the neck injury surveillance data reported by Schneiders et al. (87). Schneiders et al. (87) defined an injury as “any physical event that occurred during a match that required a player to seek medical attention from a team doctor, physiotherapist, and/or sports
medic, or miss at least one scheduled game or team training”. A previous study which analysed the severity of neck injuries has reported that the majority of injuries sustained to this region can be classified as minor (30, 36). As the majority of neck injuries are minor in severity, players may not seek treatment for these injuries or the severity of the injury may be such that the player will not miss any games or practices. The aforementioned factors prevent meaningful documentation and a potential under-representation of these injuries in surveillance studies. This potential under-representation of minor neck injuries may explain the discrepancies between the reported levels of neck pain in the current study and previously documented injury trends.

5.5.5 Neck stiffness

NS was also examined at the start and end of the season, over the competitive season, no changes in NS were observed for the forwards or the controls. Unexpectedly, the backs reported increases in NS for all three measured scales: current NS increased by 21.71 mm, average by 18.07 mm, and worst by 29.84 mm. When the changes in NS were compared between groups, the only statistically significant results were isolated between the backs and the controls for current and worst NS. The lack of change in the forwards’ NS was an unexpected result, given the demands place on the cervical region for these players. This lack of change in the NS for the forwards may be a function of the timing of the assessments. Due to the nature of amateur rugby, access to players for testing was only possible once the season had started. Forwards had therefore already been exposed to some training and or game play and may have already been experiencing some level of NS due to the larger proportion of time these players spend engaged in static forms of play (rucks, mauls, and scrums) (141). Given the mean score of 20.26 mm for the forwards and 13.47 mm for the backs and 10.35 mm for the controls, this is a feasible explanation.

5.6 Conclusion

This study was the first examination of the effect of a competitive rugby season on neck strength, endurance and self-reported NP and NS in a cohort of forwards, backs and controls. From the start to the end of the season, a statistically significant strength increase was observed in all directions for the forwards and for Ext, Flx, and LtFlx for
the backs, while the controls remained unchanged. Due to the large inter-individual variability, no changes in neck musculature endurance were observed over the season. Despite the increases observed in neck strength, both self-reported current and worst NP were found to increase for the forwards and the backs. In contrast, NS remained unchanged for the forwards and increased for the backs for all three examined VAS over the season. These findings begin to explore the potential relationship between the occurrence of minor neck injuries and the potential role neck musculature strength and endurance may play in mitigating or preventing these. Future research should be directed towards combining neck injury surveillance with assessments of the cervical musculature strength and endurance to further explore this relationship.
Chapter 6

A Neck Specific Exercise Intervention for Rugby
Chapter 6 – Design of a Neck Exercise Invention

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6.1 Introduction

In the sport injury literature, the ‘Sequence of Prevention’ has been used to describe measures that have been taken to prevent injuries in sport (21, 22). As previously discussed, this framework consists of three distinct phases: (a) injury surveillance, (b) identification of the factors and mechanisms that play a role or influence the occurrence of the observed sport injury, and (c) the implementation of prevention measures (21). In sports, the use of exercise therapy as a means to prevent injury is a practice that is often based on little scientific evidence (129). This practice extends to the prescription of neck exercises for athletes that participate in collision sports. A number of position papers have been published highlighting the importance of neck exercises for injury prevention (54-57), but little work has been done to examine the efficacy of these programs. Thus, the focus of this chapter is the design of an intervention based on evidence collected from Phase 1 and Phase 2 of the ‘Sequence of Prevention’.

6.1.1 Phase 1: Injury surveillance

The first step in the ‘Sequence of Prevention’ dictates that the frequency of the injury must be determined (21). For rugby, the incidence of neck injuries ranges from 0.5 to 10.58 injuries/1000 player-hours for professional players (30, 46, 84), 2.9 injuries/1000 player-hours for amateur players (36), and 6.1 injuries/1000 player-hours for youth rugby players (34). The reported frequency of neck injuries sustained during rugby increases with the level/grade of play (29, 36), playing position (forwards sustain more than backs), and game play when compared to training sessions (24, 27, 30).

The majority of neck injuries in rugby are classified as minor in severity, resulting in less than one week of missed play (30, 34, 36). In research examining minor neck injuries, it has been reported that one of the primary symptoms of these injuries is neck pain (NP) (64). The prevalence of NP in amateur rugby has been reported to be high (44), and although not examined at the professional level, it is expected that given the increased frequency of neck injuries for these players, the level of reported pain would potentially be higher. In addition, previous neck injury in rugby has been shown to increase the risk of sustaining future injuries to the head and neck region (30, 46, 301). In other collision sports (e.g. ice hockey), a relationship has been identified between presence of NP and concussions risk (301).
6.1.2 Phase 2: Factors and mechanisms which may influence the occurrence of neck injuries

The second stage of van Mechelen’s (21) model involves an examination of the factors and mechanism that may influence or perpetuate the frequency of these injuries. Examination of the phase of play indicates that the tackle causes six times more injuries than other types of contact events (52% of all neck injuries) (30). This outcome implies that players of all positions are at risk of neck injury. However, these findings may reflect the frequency of the tackle event during the game (average of 221.0 events per game) rather than its propensity to cause injury. When the propensity to cause injury was taken into consideration, collisions are 70% and scrums 60% more likely to result in injury than the tackle (100). To provide further support for this conclusion, injury surveillance of junior and senior amateur rugby players in South Africa during the 2008-2011 seasons reported that the scrum accounted for 42% of all acute catastrophic spinal cord injuries (24).

As the cervical musculature is primarily responsible for the spatial position and active motion of the head (86, 157), this musculature may play a role in injury prevention (53, 54). Researchers examining impact loading of the head has proposed that the sternocleidomastoid (SCM) and the upper trapezius are the primary dynamic stabilizers of the head and neck region (89-91, 157). These authors propose that during impact events, the muscle onset time and the level of contraction “likely attenuate head acceleration and/or absorb energy from direct and indirect impacts” (90). Investigation of gender differences relating to dynamic stabilization of the head-neck region in response to an external force application has reported greater head-neck angular acceleration in the female participants. The authors attributed this finding to decreased levels of cervical strength (50%), neck girth and head mass in the female participants, resulting in reduced head-neck segment stiffness during impact events when compared to males (92). To further examine the role neck girth and strength may have on injury tolerance, the National Football League (American gridiron) altered the neck stiffness of test dummies to simulate varying levels of cervical strength and neck girth. Reconstruction of impact events revealed that increased neck stiffness improved injury tolerance by up to 35% (162). Despite these findings, research examining the role of
isometric cervical strength and its relationship to kinematic data of the head and neck region during impact in sports has provided evidence to the contrary (90, 91, 147).

Head impact biomechanics were evaluated throughout a season in 37 youth ice hockey players using helmets instrumented with accelerometers. No relationships were found between isometric cervical strength and linear or rotational acceleration during impact, which contradicts the notion that the cervical musculature mitigates head impact acceleration (147). Other authors have examined the impact of an 8-week neck specific intervention on dynamic head-neck segment stabilization in soccer players (91) and head kinematics during an American gridiron tackle in high school players (90). Both studies reported gains in cervical strength and no change in dynamic stabilization of the head-neck region (90, 91). Rather than examining the relationship between neck strength and head acceleration during impact, a recent study assessed the effect of strength imbalances between the cervical extensors and flexors, and the role these played in head acceleration during a soccer-heading task. The study authors reported that the mean strength difference was correlated positively with angular head acceleration during a low velocity-heading task, with a trend towards a statistically significant positive correlation for linear head acceleration (89). These findings would suggest that attaining a balance between the agonist and antagonist muscle groups in the neck may play a larger role in improving dynamic neck stabilization than in improving peak force production.

6.1.3 Phase 3: Neck exercise intervention

The above findings highlight the potential role that the cervical musculature may play in the prevention or minimization of minor non-catastrophic neck injuries in rugby. The use of exercise interventions to improve muscular strength, endurance, fitness, individual and team skill performance in sports is in many cases an evidence-based practice (129). In addition to improved muscular performance and skill acquisition, exercise interventions are commonly used for the prevention or minimization of injury in many sports (91). In many cases, there is little research support for this practice with the exception of lower limb and shoulder injuries, in particular prevention strategies aimed to reduce the frequency of anterior cruciate ligament injuries (218-220). For neck injury prevention, there are a number of position papers that have recommended the inclusion of neck specific exercises to prevent or minimize the severity of neck injuries.
in rugby or other collision sports (27, 54, 56, 57, 129, 221) despite the lack of scientific evidence to support these claims (221). In the concussion prevention literature, Cantu et al. (53) proposes that strength training of the cervical musculature may enhance the energy absorption capacity during impact and thereby minimizing concussion severity. Literature on neck injury prevention has hypothesized that the primary role of cervical strength training is to minimize the severity of injuries to this region, specifically minor injuries (54).

These authors highlight the importance of including neck specific exercises in the normal training routines of athletes in collision sports. This inclusion, however, raises the question of whether participation in these sports provide sufficient stimulus to the neck musculature to generate strength improvements, or are supplementary exercises that target the neck required. This question has not been examined in the context of collision sports. As highlighted in Chapter 5, high level amateur rugby players displayed improvements in neck muscle peak force measurements over the season. This finding could be interpreted in conjunction with injury surveillance data of rugby players participating in the same grade of play, where it was reported that injury frequency decreased over the season (87). These findings could suggest that neck musculature peak force improves with participation and provides some protective effects that reduced the frequency of neck injuries in this population. Despite the potential relationship between improvements in neck peak force and neck injury reduction (Chapter 5)(87), an increase in neck pain was documented for both the forwards and backs over the season (Chapter 5). In addition to the increases in neck pain, the backs also reported increases in neck stiffness over the season (Chapter 5). This finding suggests that the frequency of minor neck injuries, which could be missed in an injury surveillance assessment, increased over the season. Performing neck specific exercises may help to prevent or mitigate these symptoms of NP and NS for this cohort of rugby players, thus warranting further investigation.

To determine whether neck specific exercises were necessary to produce improvements in peak force or changes in cross-sectional area of the cervical extensors, a study compared the effect of a conventional resistance training program in two groups of participants. Both groups were prescribed the same general resistance training program. However, one group performed an additional 3 x 10RM neck extension exercises. The
provision of a conventional resistance program without neck specific exercises elicited no change in cervical extension strength or increase in cervical extensor cross-sectional area. In contrast, those completing the neck extension exercises achieved a 13% increase in the total cross-sectional area of the cervical extensors and a 34% increase in Ext MVC. These findings suggest that the isometric load imposed on the cervical musculature during conventional resistance training fails to elicit neuromuscular changes in the neck musculature (39). Therefore, neck specific exercises appear to be needed to stimulate increases in cervical musculature cross-sectional area and peak force.

This chapter describes the theoretical rationale behind the design of a neck specific intervention for rugby players. The intervention program incorporates exercises that focus on four key areas: (a) neck muscle strength, (b) neck muscular endurance, (c) neck muscle coordination, and (d) impulse loading of the neck. The following sections discuss each of the components in detail.

6.2 Neck Muscle Strength

Cervical musculature peak force has commonly been used as an indicator of neck muscle dysfunction (58, 163) with a number of studies on different populations reporting strength decrements in individuals with NP (6, 40, 65). In contrast, in studies where neck specific interventions have produced documented improvements in force, no subsequent reductions in NP have been shown (72). In the face of conflicting evidence, there is little consensus between clinicians and researchers regarding the relationship between NP and neck strength. However, researchers appear to agree on the use of these variables to determine training dosage and to document rehabilitation efficacy (58, 165).

From an injury prevention perspective, enhanced cervical strength in collision sports has been proposed as a viable mechanism to minimize injury frequency (26, 36, 52, 53, 55-57, 75). It has been postulated that enhanced cervical strength could attenuate head acceleration and/or dissipate energy from direct and indirect impacts during contact events (73, 90). As reported above, work by Tierney et al. (92) examining gender differences supports this link, and (162) has demonstrated through simulations that increased neck strength could improve injury tolerance. It is hypothesized that an
increase in the cross-sectional area of the neck musculature has the potential to provide increased stability to the cervical spine, functioning to limit or prevent musculoskeletal impairment (168). Given that 80% of cervical stabilization is provided by the cervical muscles (115), improving the force production from these muscles could contribute to enhanced stabilization of the cervical spine.

During the contact engagement in the scrum, the neck musculature works in an isometric fashion to stabilize the cervical spine against the resultant force production (151). Given the forces experienced in the scrum (two-thirds of a tonne across the front row players), high levels of neck strength would be required to maintain the stability and alignment of the neck (76, 151). Although the scrum is one of the phases of play with the highest risk of neck injuries per event (24), the majority of neck injuries are sustained during the tackle (30, 36). Research examining neuromuscular response during low velocity collisions indicates that the cervical musculature may help to dampen the deceleration of the neck into the end range positions that cause damage to the soft tissues of the neck during tackling events (152, 153, 157, 158). It stands to reason that the inclusion of isometric exercise in the neck specific program for rugby players is important as it simulates contractions performed during the game, particularly for those in the forward positions and front row.

Strength training is a mechanical stress that stimulates various adaptations of the neuromuscular system, the most notable being increases in muscle size and strength (39). These adaptations are related to the characteristics of the specific exercises employed in the training program. “This is referred to as the ‘specificity of training’ and suggests that the greatest gains in strength are observed in activities similar to the ones used in training” (39)p. 444). The provision of an exercise program consisting of a strength component has the capacity to increase the isometric strength and endurance of the cervical muscles (72, 195, 302). The ability of a muscle to generate force is related to the cross sectional area (303, 304); which includes the cervical musculature (162, 294). It is hypothesized that an increase in the cross sectional area of the neck musculature has the potential to provide increased stability to the cervical spine, functioning to limit or prevent musculoskeletal impairment (168). Given that 80% of cervical stabilization is provided by the cervical muscles (115), improving the force
production from these muscles should theoretically lead to enhanced stabilization of the cervical spine.

In rugby, support for the use of neck specific interventions is limited to position papers (56, 57, 234), or a single case study (88) that focused on the use of isometric neck strength exercises. Other research has examined the efficacy of a neck strength program versus a cervical muscular endurance program in a sample of 180 female office workers over a year. Participants assigned to the strength intervention improved their maximal neck strength by 110% for Flx, 69% Ext, and 76% rotation. The respective improvements for the endurance group were 28%, 29%, and 16%, and in the control group were 10%, 10%, and 7%. Relative to the endurance and control groups, the strength training group was the only group where statistically significant increases in lateral flexion, Flx, and Ext were achieved (42). Ylinen et al. (94) showed that the greatest gains in neck strength coincided with largest decreases in NP and disability as illustrated by the negative linear association between NP and disability indices with improved isometric neck strength. These findings are further supported by Randløv et al. (305) who evaluated the efficacy of a high vs low intensity neck exercise program on subsequent NP scores associated with the activities of daily living. They found reductions in NP scores only for subjects in the higher intensity program and not in the lower intensity program after a 12-month follow-up period. In contrast to the previous results, a study by Nikander et al. (40) using a similar population reported that both strength and endurance training decreased perceived NP and disability equally regardless of intervention assignment. Nikander et al. (40) found a 20 mm decrease in NP on the visual analogue scale for those who trained for more than 8.75 metabolic equivalent hours (MET•h-1) per week, or 35 MET•h-1 of training per month. The greater the training adherence, the larger the reduction in NP symptoms. However, all participants who complied with more than 35 MET•h-1 per month belonged to the resistance training group; “[i]t may be more probable to complete 40 min of specific higher-load strength exercises than 60 min of endurance training with 2 kg dumbbells” (40).

Other research examining fighter pilots has demonstrated that both trampoline and strength training have shown positive effects on the cervical spines through decreases in muscle strain experienced in-flight and during cervical loading tests. After a three
month follow-up, the improvements in muscle strain remained for both training interventions (306). In contrast, a 6-8 month study of Swedish fighter pilots found increased strength and endurance in the neck musculature after completing a supervised neck specific strength training program, but no reductions in NP were reported (72). These findings highlight the potential impact improvements in neck strength can have for the occurrence of NP symptoms and the prevention of minor neck injuries for rugby players.

In summary, the evidence suggest that neck strength for rugby players may play an important role in withstanding the forces experienced in the scrum and enhancing dynamic stabilization of the neck during impact events. Research examining the efficacy of neck strengthening exercises indicates:

1. Greatest decreases in NP and disability coincide with the largest improvements in peak force production (40, 42, 43, 172, 305).
2. The largest decreases in NP were achieved by those individuals with the greatest training adherence (40).
3. Increases in neck circumference/cervical strength have been shown to enhance dynamic stabilization of the head-neck region (92, 162).
4. Linear head acceleration during low velocity impacts was positively correlated to the strength discrepancy between the cervical flexors and extensors (89).

Based on this evidence, neck strength exercises were incorporated into the design of a neck intervention for rugby players. An initial resistance load of 50% of each participant’s MVC was used (88). Due to the documented presence of pathological changes to the osteoligamentous system of the cervical spine (47, 83), all exercises were conducted in a neutral position to limit the potential for injury. Contractions were held for 15 s for 3 reps with 15 s rest between reps for each direction. If during the pre-season assessment, large strength discrepancies were observed between the flexors and extensors or the left and right lateral flexors, an extra rep was prescribed for the weaker side. Every two weeks the length of the hold was progressed by 5 s up to a maximum of 30 s. Once this maximum was achieved, the resistance load was increased by 5% and the time was dropped back to 15 s. Initially these exercises were conducted in a seated position. However, as the program progressed into the regular season, these positions were modified to reflect position specific demands see Figure 6.1. These exercises
were also conducted using theraband tubing where participants were asked to stand or were placed in 4-point kneeling. Bridges against the wall or ground were also used.
Figure 6.1: Exercises comprising the isometric strengthening component of the neck intervention program. Top left: Front bridge with chin tuck; Top Right: Back bridge with chin tuck, Middle left: Isometric extension hold in a simulated squat stance; Middle right: Isometric side flexion hold; Bottom: Isometric side flexion hold in a simulated scrum posture.
6.3 Neck Muscular Endurance

In comparison to research examining neck strength, fewer studies have focused on neck muscular endurance (58, 163). These studies report higher variability with this measure due to factors such as motivation and muscular fatigue that modulate the performance of sustained contractions (59). Despite these factors, impaired endurance capacity and reduced neuromuscular efficiency of the cervical musculature is a commonly reported finding in individuals with NP (64, 163, 164). Research examining muscle fatigue has indicated that it may be a major risk factor in the development and occurrence of muscle injuries (59, 164). In research examining neck muscle fatigue in aircrews, it has been suggested that fatigued muscles increase the risk of neck injury and have the potential to reduce mission effectiveness (68, 78, 164). Loading factors such as posture, whole body vibration and increased head mass have been found to contribute to fatigue in the cervical musculature during flight (77, 203, 307). In collision based sports, the impact of neck muscular fatigue has not been examined. In rugby, the frequency of neck injuries increases as the game and as the season progress (30, 36), which could potentially implicate cervical muscular fatigue as a risk factor. In addition to neck injuries, the high level of documented NP in amateur rugby (44) may indicate the presence of impaired endurance and neuromuscular efficiency.

Numerous studies have illustrated reduced cervical endurance capacity in the extensor and flexor muscles in individuals with NP (61, 66-68, 70, 78, 121, 122, 172, 308). Falla et al. (67) assessed the muscular fatigue of the superficial flexors, SCM and the anterior scalene (AS) during sustained cervical Flx contractions at 25% and 50% of the MVC in patients with chronic NP. Individuals with NP manifested greater myoelectric fatigue in the SCM and AS muscles relative to the controls. These results were observed for contractions at both 25% and 50% of MVC, demonstrating greater fatigability in the cervical flexors of individuals with NP. Gogia and Sabbahi (123) similarly established greater cervical flexor muscle fatigability during low load sustained contractions (25% MVC). It has been proposed that the greater level of muscle fatigue documented in NP patients can be attributed to an increase in the concentration of Type II fibres in the examined muscles (67). Muscle biopsy studies in individuals who reported NP have observed an increased concentration of the Type-IIIC transitional muscle fibres in the neck flexors, resulting from the transformation of slow-twitch Type I oxidative fibres to
fast-twitch Type IIB glycolytic fibres (309). This increase indicates that for individuals suffering from chronic NP, there is a transition towards more glycolytic properties in the muscle fibres of the neck muscles which would result in impaired endurance performance in these muscles (67, 309).

The effect of a 6-week endurance-strength training regime consisting of progressive resistance exercises for the cervical flexors was examined with individuals with chronic NP. Over the six weeks, participants completed a dynamic cervical Flx exercise two times per day. For the first two weeks, participants completed 1 set of 12-15 reps using a resistance load of 12 RM, and for weeks 3-6 the number of sets was increased to three. Post-intervention, an increase in cervical Flx force and a decrease in the initial value and rate of change of the mean spectral frequency for the AS and the SCM were observed. In addition to these documented neuromuscular improvements, decreases in average intensity of NP and the NDI score were also achieved. These findings indicate that an endurance-strength based cervical Flx exercise program is successful in reducing myoelectric manifestations of muscle fatigue in the SCM and AS and improving Flx peak force production (214).

Endurance training focuses on improving the ability of muscles to continue prolonged submaximal work (59, 164). Previous research conducted using a sample of fighter pilots compared the effects of a weighted helmet training program versus a dynamic neck endurance program. The pilots assigned to the dynamic endurance training program had fewer workdays lost and restrictions in +Gz flights than the weighted helmet group. However, isometric neck muscle strength increased irrespective of training group status, and no differences were identified in the passive cervical range of motion (195). The limited sample size and the lack of a control group in this study limited the generalizability of these findings.

Alricsson et al. (72) evaluated the impact of a 6-8 month intervention that was comprised of strength and endurance exercises for the neck and shoulders in fighter pilots. The exercises for the neck were conducted using weights placed on the head or weights attached to a training helmet, using a training load of 4 sets of 10 reps that was progressively increased over the length of the program. Post-intervention those assigned to the intervention group demonstrated improvements in Ext (5.0 Nm) and Flx (3.9 Nm) torque, while the control group remained unchanged for Flx strength and
decreased their Ext strength (-11.5 Nm). In contrast, a 12-week intervention study examined the effectiveness of dynamic endurance based program in helicopter aircrew. The intervention consisted of dynamic Ext, Flx, LtFlx and RtFlx exercises with a training load of approximately 30% MVC for three sets of 12 reps using rubber tubing and a custom head harness. At the end of the 12 weeks, no changes in Ext and Flx peak force were observed but a 23.40 N improvement in RtFlx was recorded. However, this study also contrasted the effectiveness of this intervention relative to a muscle coordination program that focused on low load exercises targeting muscle control to train and re-establish muscle coordination in the cervical spine. The first two phases of this coordination program targeted retraining the muscle activation pattern of the deep and superficial cervical muscles. The third phase consisted of similar exercises as the endurance based program. At 12-weeks, those assigned to the coordination program achieved improvements in Flx and RtFlx peak force, in addition to the submaximal endurance trial times to fatigue for LtFlx an RtFlx (71). These findings would suggest that the combination of endurance and muscle coordination exercise resulted in the largest improvements in neck muscle peak force and submaximal endurance.

As the frequency of neck injury for professional players increases as a game and as the season progresses (20, 30, 100), neck muscle endurance may present a feasible strategy to reduce or prevent the occurrence of minor neck injuries. In addition to these reported injury trends, research has documented the following:

1. Impaired endurance performance of the cervical musculature in individuals with NP (61, 66-68, 70, 78, 121, 122, 172, 308).
2. Loading factors contribute to cervical musculature fatigue (77, 203, 307).
3. Improved neuromuscular function of the cervical muscles following the prescription of an endurance exercise program (71, 72, 195, 214).
4. After a dynamic endurance neck exercise program, fighter pilots had fewer work days lost and restrictions on +Gz flights (195) and helicopter pilots reduced self-reported scores for ‘worst NP’ (71).

As neck injuries at the professional level have been found to increase as the season and the game progress (20, 27, 30), cervical musculature fatigue has been identified as a potential risk factor. As a result of these findings a component of the neck exercise intervention focused on the incorporation of low load dynamic endurance exercises. For
these exercises participants used elastic rubber tubing (Theraband, Hygiene Corp, Akron, OH) to resist the dynamic movements of cervical Flx, Ext, RtFlx and LtFlx. To achieve this participants assumed a seated position wearing a 2.5 cm webbing head harness to which rubber tubing was attached via carabineers that was equivalent to their 30% MVC determined during pre-season testing. The resistance was provided by rubber tubing that was cut to 70 cm length. The approximated stretch on the rubber tubing was 25%. The tubing resistances were calculated to be: blue (3 lbs), black (4 lbs), and silver (5 lbs) (71, 93, 181). For the extension direction, the tubing was attached via a carabineer to a weighted mount on the floor in front of the participants. For the flexion direction, the participants turned the chair in the opposite direction and the tubing was attached to a clip on the back of the head harness while the opposite end remained attached to the same floor mount. Left and right lateral flexion required the participants to attach the tubing to the clips located on the left and right sides of the head harness. For the lateral flexion directions, the participants were asked to hold the tubing with the same hand with their arm abducted and their elbow bent to 90° (Figure 6.2) (6, 71).

For all the exercises in this component individuals were instructed to perform the movements with a slight chin tuck in a slow controlled manner. For each of the four directions, participants performed 3 sets of 10 reps maintaining a resistance level of approximately 30% MVC (40, 168). One minute of rest was given between each set (40, 42, 168). If a participant was able to perform 12 consecutive reps of an exercise, the load was increased by 5% as necessary to maintain 10RM on subsequent performed sets. A rhythmic cadence of 2 s for concentric and eccentric contractions was maintained (6, 40, 42, 71, 168). At the end of range of motion, the contraction was held for 1 s (93). Timing for the cadence was provided by the exercise physiologist (72).
6.4 Neck Muscle Coordination

The primary role of the cervical musculature is to stabilize the vertebrae in a neutral and mid-range postures. If loading events occur when the cervical spine is in a neutral posture, these forces can be distributed to supporting structures (muscles and ligaments) to limit force dissipation at the cervical vertebrae (174). This phenomenon is achieved through the passive tone maintained by the cervical musculature (310, 311). The muscles surrounding the cervical vertebrae of the spinal column are classified as segmental stabilizers, which provide postural support for cervical lordosis and the cervical joints (119). The superficial and intermediate layers of the cervical muscles are known as prime movers, whose primary role is movement of the head and cervical spine (120).
Individuals with NP demonstrate the following neuromuscular patterns: (a) greater fatigability of the superficial prime movers, (b) impaired neuromuscular efficiency of the superficial prime movers, and (c) impaired recruitment of the deep cervical flexors that appears to be compensated for by increased superficial muscle activity (61, 67, 123, 125) (69, 70) (126) (5, 68). These muscle deficits may develop rapidly following the occurrence of NP and have been documented to persist despite the resolution of the pain symptoms (55, 249). A long-term follow-up study examined muscle recruitment patterns in the cervical spines of 65 acutely injured whiplash patients. Three to six months post-injury, those individuals reporting mild to severe NP continued to demonstrate altered muscle recruitment patterns (312). An additional follow-up study was conducted on these same individuals two to three years later and these changes in cervical motor function remained (249). For those individuals at the follow-up who were not currently experiencing NP, 11 out of the 23 reported intermittent NP episodes which they did not experience prior to the injury. Comparisons were conducted between these individuals and the only persistent deficit that could be detected for those still experiencing episodic NP was the altered cervical muscle recruitment patterns (249).

In the literature regarding altered cervical muscle recruitment patterns, the deep neck flexors (DNF) have received considerable attention (54, 55, 85). Research has documented an association between DNF muscle performance and disorders of the neck encompassing chronic NP, headaches, and acute traumatic injuries to this region (5, 62, 69, 70, 78, 128, 210). The DNF surround the cervical vertebrae of the spinal column and are classified as segmental stabilizers, that provide postural support for cervical lordosis and the cervical joints (119). In addition, the DNF facilitate flexion of the head and neck, act as a protective cuff surrounding the cervical vertebrae in conjunction with the posterior cervical muscles, and help stabilize the cervical spine in anticipation of movement (85). In individuals who report NP or have sustained a whiplash injury, activation of the DNF is often impaired, with compensation provided by the superficial flexors, in particular the SCM and AS (67, 69, 70). It has been proposed that this inefficient pattern of muscle recruitment plays a role in the perpetuation of symptoms and/or the reoccurrence of NP episodes (125).
These altered muscle recruitment patterns observed in individuals with NP are not limited to the DNF and the superficial cervical flexors (311). Increased activation levels (313, 314) and delayed muscle onset times following the commencement of activity have also been documented in the superficial cervical extensors in individuals with NP (313). Consistent with the pattern observed for the anterior cervical musculature, recent work using muscle functional MRI has documented reduced activation levels in the deep cervical extensors in participants with NP (315). These reduced activation levels have been confirmed using intramuscular EMG recordings in the semispinalis cervicis (311). Based on this evidence, inclusion of exercises that target the muscle activation patterns of the posterior cervical musculature have been highlighted as essential for the rehabilitation of individuals with NP (80, 311).

The inclusion of neck muscle coordination exercises into neck specific intervention programs was proposed in a review on the complexity of muscle impairment in chronic NP conducted by Falla (61). In a cohort of Swedish military helicopter pilots, Ang et al. (65) examined the use of deep neck flexion exercises progressing to flexion and rotation endurance-strength neck exercises in combination with scapular stabilizing exercises. The prescription of these exercises for a 6-week period was effective in reducing self-reported NP in the ‘past week’ and during the ‘previous three months’. Post-intervention a reduction in the neuromuscular activity of the SCM during the C-CF test was also isolated (65).

In rugby, large axial forces can be applied to the vertex of an athlete’s head when they make contact with the ground or with another player (26). In a neutral cervical posture, the cervical spine has a lordotic curve. In this position, the paravertebral musculature and the vertebral ligaments in the neck are able to dissipate the forces that are transferred to the head (115). However, when the neck is slightly flexed, the cervical spine behaves as a segmented column with the vertebral bodies of the cervical spine lined up under one another. If an impact to the vertex of the head is sustained in this posture, large amounts of force would be transferred to the cervical vertebrae (longitudinal axis). Minimal force dissipation by the musculature and ligamentous system would occur given the position of the cervical vertebrae (segmented column), placing the individual at risk of an injury such as a fracture, break or facet dislocation (57, 97, 150). If during contact situations the individual is able to maintain a neutral
spine, the cervical musculature and ligaments can function to dissipate some of the axial compressive force, potentially mitigating or minimizing the severity of injury.

Given the large role the deep cervical stabilizers play in supporting and stabilizing this neutral cervical posture (61, 120, 183), a number of position papers have proposed the inclusion of exercises that target the deep cervical musculature for athletes involved in collision based sports (54, 55, 85). Currently, the efficacy of these exercises has not been examined in athletes involved in collision based sports. In summary, the research suggests:

1. Individuals with NP present with altered neuromuscular recruitment patterns, with decreased activation of the deep cervical stabilizers compensated for by increased activation of the superficial musculature (5, 61, 67-70, 123, 125, 126, 208).
2. Following injury to the neck, altered neuromuscular recruitment patterns remain for prolonged periods which may explain the perpetuation of NP symptoms (249, 312).
3. Deep cervical stabilizers play a large role in maintaining a neutral cervical posture, which during impact events may unload the vertebrae (26, 115, 316).
4. Inclusion of muscle coordination neck exercises in an intervention have resulted in improvements in neck muscle peak force (6, 71), endurance (65, 71) and decreased levels of self-reported NP (65, 71, 180).

For this component of the intervention, the focus was on low load exercises to train the coordination between the layers of cervical muscle (61). In contrast to the endurance training program, this exercise regime used low load exercises to train and re-establish coordination between the deep and superficial layers of the neck musculature. Once the imbalance between deep and the superficial muscle was addressed, general neck strengthening exercises were introduced (69). The first aspect of this program focused on muscle control, where low load exercises are used to enhance the coordination between the layers of cervical musculature (61). This motor control aspect “is based on biomechanical evidence of the functional interplay of the deep and superficial neck muscles and on the physiological and clinical evidence of impairments in these muscles in NP patients” (61). The first stage of training targeted specific exercises designed to isolate the deep segmental cervical stabilizers that support and maintain the neutral
cervical lordotic curve (71, 86). The second stage integrated limb motion while the deep segmental stabilizers were challenged to maintain a neutral cervical spine (54, 86). The third and final stage focused on the interplay of the deep stabilizers and the superficial prime movers. The deep stabilizers were required to support the neutral lordotic curve of the cervical spine while the superficial musculature was employed to segmentally control neck motion (71, 120).

The exercises for this component of the program were developed with the guidance of physiotherapist, Carol Kennedy, who specializes in exercise prescription for patients with cervical spine dysfunction. Two stages of progression were employed for this component of the program. The first stage of this training program focused on isolating the deep segmental stabilizers (flexors and extensors) of the cervical spine. The primary exercises of this intervention stage used isometric contractions to maintain a neutral cervical spine (slight lordosis of the cervical spine) in supine, standing and sitting. Other exercises in this initial stage focused on proper segmental movement of the deep extensor cervical musculature in a return to neutral posture in a four point kneeling and a sitting position. Stage two focused primarily on maintaining a neutral cervical spine while integrating limb motion into the exercises. The exercises consisted of the windmill, internal and external shoulder rotation and return to neutral posture in four point kneeling with pure rotation (55, 71, 120).

For each of these exercises participants were instructed to perform all movements in a slow and controlled segmental manner. Throughout the exercises they were provided with continual feedback to maintain and slight chin tuck to engage the deep cervical stabilizers. For the exercises that included isometric holds participants were initially prescribed 5-10 s holds for 10 reps. When the participant was able to maintain the 10 s hold for 10 reps, the reps were decreased to five and the timeframe for the holds was increased to 15 s. This progression in the reps and holds was used throughout the season. Figure 6.3 illustrates a selection of the exercises employed for this neck muscle coordination training component of the exercise program.
Figure 6.3: Exercises used in the neck muscle coordination training component: Top left: Deep neck flexor head nod; Top right: Deep neck flexor head nod with head lift; Middle: Seated return to neutral; Bottom left: Return to neutral in four point kneeling, Bottom right: External shoulder rotation (71)
6.5 Impulsive Loading Using Low Level Resistance in a Neutral Neck Position

This component of the program was based on the recommendations of Mansell et al. (91) who suggested plyometric training of the neck and shoulder segment may stimulate the neuromuscular changes necessary to enhance head-neck segment dynamic restraint during impulse loading. As the tackle, an impulse loading event, is responsible for the majority of neck injuries (30, 36, 87, 100), incorporation of a dynamic stabilization component in the program was viewed as essential. Dynamic stabilization of a joint is dependent upon both feed-forward and feedback mechanisms to coordinate movement patterns in anticipation of and in reaction to movements or the application of a load (91). As previously highlighted, co-contraction of the SCM and the trapezius muscle prior to the application of an impulse load has been shown to reduced head displacement and acceleration through feed-forward mechanisms (130, 153, 157, 158). The feedback mechanism of control relies on reactive muscle activation and uses neural reflex pathways to regulate movement (91). These reflex responses in the cervical region are regulated by sensory input received by the vestibular, visual and mechanoreceptors in the head and neck (158, 228). Hypertrophy of the cervical musculature has been documented in response to the implementation of a neck specific progressive resistance training program (39). More importantly, resistance training of this musculature may provide a functional stimulus to improve neuromuscular recruitment patterns and control (51), thereby increasing the rate and amount of muscle force development (91, 225). This improvement in the rate and amount of force development in the muscles of the cervical spine may translate into potential protective effects that lessen the severity or frequency of minor neck injuries.

Two intervention studies have examined the effects of cervical strength on head kinematics during a dynamic stabilization task in soccer players (91) and during a tackle in American gridiron players (90). In the dynamic stabilization task, soccer players were divided into either a resistance training or control group that were assessed pre- and post-intervention. The dynamic stabilization task required participants to sit inside a device wearing a head harness that was attached to a pulley system with a 50 N load on the opposite end. Their head and neck segments were impulsive loaded over a series of trials where knowledge of the impulse loading event was manipulated by the
researcher. The main outcome variables of interest were the head-neck segment kinematics and stiffness, EMG activity of the upper trapezius and SCM muscles and isometric peak force in Ext and Flx. The resistance training group incorporated neck specific exercises two times per week for 8-weeks into their regular gym training routines. After completion of the post-intervention assessment, the authors reported no reduction in head-neck segment acceleration in the resistance trained group despite an improvement in Flx peak force of the males. For the male participants, no changes in muscle onset times for the SCM or the upper trapezius were observed. The authors concluded that these findings indicate the need for “neck muscle training tasks that elicit feed-forward and feedback motor control mechanisms to better use dynamic stabilizers for both protection and performance enhancement” (91). Although not included in this intervention, research looking at other regions of the body has reported that ballistic activities (plyometrics) resulted in enhanced neuromuscular control and dynamic stabilization (225-227).

A similar study investigated the effects of an 8-week isoinertial cervical resistance training program on head and neck kinematics and neuromuscular activity of the SCM and upper trapezius during an American gridiron tackle using EMG and a ViconNexus® 3D motion capture system. The intervention consisted of isoinertial Ext, Flx, RtFlx, and LtFlx exercises at a resistance load of 60-80% of the 10RM for 3 sets of 10 reps 2-3 x per week. Post-intervention improvements were observed for Ext (7%) and LtFlx (10%); however, these changes failed to augment the neuromuscular response of the SCM or upper trapezius, peak linear or angular head acceleration during the tackling task (90). Consistent with the previous study, the authors proposed the exercises in the intervention failed to emphasize hypertrophy, muscle contraction velocity, and muscle co-contraction of the SCM and upper trapezius, which potentially explains the lack of statistically significant findings. Another limitation was the linear acceleration values recorded during the tackling tasks which ranged from 7.23-7.59 Gz (90). These values for American gridiron players are lower than the average values recorded during tackling events at the high school (23-25 Gz) (229) and collegiate (21-32 Gz) levels (144-147). As the linear acceleration values of the head obtained during this study did not exceed 8 Gz, the level of dynamic stabilization provided by the cervical musculature may have been sufficient to withstand the impulsive load imposed by the tackling task.
As the majority of neck injuries in rugby are sustained during the tackle (30, 36), an impulsive loading event, incorporation of exercises that focused on preparing and training the neck musculature to cope with these events was considered essential. The research surrounding impulsive loading of the neck indicates the following:

1. Existence of a correlation between neck strength and angular head-neck acceleration (92, 162).
2. Improved neck strength resulting from the application of isotonic neck exercises did not improve dynamic stabilization of the neck (90, 91), indicating the need for neck specific exercises that incorporate feedback and feed-forward motor pathways.
3. Co-contraction of the cervical muscle prior to impact has been found to reduce linear head acceleration following low velocity impacts (152, 157, 158).

Based on this evidence, low load impulsive neck exercises were incorporated into the design of the exercise program. For these exercises, a low level of resistance was used to perturb the dynamic stabilization of the cervical spine. Participants were instructed to co-contract the muscles of the cervical spine to maintain a neutral position with a slight chin tuck throughout. Exercise positions varied from 4-point kneeling, to standing, to a simulated contact position. Exercises were typically held for a period of 30 s and range from 2-3 reps for 1-3 sets. For each exercise, participants were aware of the direction the impulse event would be applied. These exercises were typically performed at the end of the program when the cervical musculature was already pre-fatigued. An illustration of a few exercises employed for this component of the program is provided in Figure 6.4.
Figure 6.4: A selection of exercises used to impulsively load the neck. Top left: Impulsive loading of side flexors in standing using theraband; Top right: Impulsive loading of flexors and side flexors in neutral neck position with partners providing impulsive force; Middle left: Adoption of a simulated contact position where participant applies force on partner’s hip with head and then switches sides; Middle right: Impulsive loading applied in 4-point kneeling in extension with theraband as resistance; Bottom left: Impulsive loading of flexors in a neutral neck posture in 4-point kneeling with resistance applied by partner using towel over forehead; Bottom right: Impulsive loading using grappling technique with partner applying force on the back of the head.
6.6 Conclusion

To further support the use of neck exercise interventions for the prevention and mitigation of neck injuries, authors of a recent study conducted a two year retrospective analysis examining the effectiveness of a 26-week isometric neck specific intervention on reducing the number and severity of cervical spine injuries in a professional rugby squad \((n=27)\). The first year of the study, 2007-08 season, functioned as the control, and the intervention was implemented over the following 2008-09 season. The intervention consisted of two 13-week mesocycles, the first mesocycle focused on strengthening, while the second mesocycle progressed participants into a maintenance phase. The selection of neck specific isometric exercises ranged from non-specific to position specific exercises that incorporated different body and upper limb positions. The 12 neck injuries sustained during the 2007-08 season decreased to 6 in the 2008-09 season, however this decrease was not statistically significant. A similar finding was observed for time lost due to injury, measured as the number of trainings and games missed due to neck injury, with 100 days missed during the 2007-08 and 40 days missed in 2008-09 season. Further analysis into the occurrence of these injuries revealed a statistically significant decrease in the number of match injuries sustained with 11 reported in 2007-08 and 2 in 2008-09 \((73)\). In addition to the injury surveillance data, pre-season and week five assessments of isometric neck strength were conducted. The authors reported a statistically non-significant increase in neck strength for Ext, Flx, LtFlx and RtFlx. However, the small sample size and the lack of a post-season assessment make it difficult to attribute the decrease in injuries to improvements in cervical musculature function.

The neck specific intervention consisted of four key aspects: (a) neck strength, (b) neck muscular endurance, (c) neck muscle coordination, and (d) impulse loading of the neck. The first component, neck strength, has been highlighted as important for collision sports \((27, 53, 56, 57, 76, 88, 90, 129)\), particularly given the potential to experience high +Gz at the head and neck region during collisions \((90, 146, 154)\). For professional players, the frequency of neck injuries increases as the game and the season progress \((36, 100)\), implicating neck muscular fatigue as a potential risk factor for the occurrence of neck injuries. Given this finding, neck muscular endurance was also incorporated into the intervention. The neuromuscular recruitment patterns in the cervical
musculature for individuals with NP from the general population (61, 67, 69, 125, 180, 183), fighter pilots (172), helicopter pilots (68, 78, 172) and individuals who have sustained a whiplash injury as a result of a motor vehicle accident (249) have been shown to be altered when compared to health controls. Given the high level of NP documented in amateur rugby players (44), we expect similar or higher levels in professional players given the higher frequency of neck injuries (30, 36). It is therefore likely that professional players with NP will also present with altered neuromuscular patterns; thus, a component of the program also targeted the coordination patterns of the cervical musculature. The final component of the program addressed the finding that the majority of neck injuries are sustained during the tackle (20, 24, 30, 36), a high +Gz impulse loading event. Research examining impulse loading of the neck in football (89, 91) and American gridiron (90) have suggested that impulse loading activities (ballistic activities such as plyometrics) may enhance neuromuscular control and dynamic stabilization of the cervical region. These activities made up the final component of the neck specific intervention program, which can be viewed in full in the attached CD.
Chapter 7

A Controlled Examination of a Neck Exercise Intervention in a Professional Rugby Team
7.1 Introduction

The use of exercise interventions to improve muscular strength, endurance, fitness, and skill performance is an evidence-based practice in sport and recreation (129). In addition, to improved muscular performance and skill acquisition, exercise interventions are commonly used for the prevention or minimization of injury in a number of sports (91). In many cases, there is little scientific evidence to support this practice with the exception of lower limb and shoulder injuries, in particular prevention strategies aimed to reduce the frequency of anterior cruciate ligament injuries (218-220).

In rugby, the cervical spine is potentially and repeatedly exposed to situations where forces are produced and encountered that can result in either severe or minor spinal injuries (27). Typically, the ligamentous and muscular system are able to absorb and dissipate these forces through controlled motion. Injury occurs when the neck position, weakness in the muscular or ligamentous systems, or structural deformities compromises the ability to dissipate these forces (53). Thus, the occurrence of neck injuries and factors or mechanisms which may precipitate these events are critical issues faced by athletes, medical and coaching staff in collision sports given the potential for permanent neurological damage or in rare cases death as a result of injuries to this region (18, 20, 29, 97, 111, 255). Injury surveillance data indicates that once a player has sustained a neck injury, they are at an increased risk of sustaining future potentially more severe neck injuries (30, 36). The potential for damages sustained during these recurrent injuries to the neuromuscular or osteoligamentous system of the neck progressing to the development of pathological changes in the region of the spine is an area of concern (47, 83, 98).

The musculoskeletal system of the cervical spine is one of the most complex and dynamic systems in the human body. Panjabi and colleagues found that the osteoligamentous system contributed 20% to the overall stability of the neck while the remaining 80% was provided by the surrounding neck musculature (115). The muscles of the neck provide dynamic support to the cervical spine for activities around the neutral and mid-range postures (61). If the cervical musculature can play a role in injury prevention, it is essential to understand the link between muscular weakness and injury or the primary symptom of minor neck injuries, NP.
Research examining neck injury prevention in collision sports is limited to a number of position papers that have recommended the inclusion of neck specific exercises to prevent or minimize the severity of neck injuries in rugby or other collision based sports (27, 54, 56, 57, 129, 221), despite the lack of scientific evidence to support these recommendations (221). However, there is a growing body of evidence to support the use of neck specific exercises in the general population (55). In a systematic review examining the conservative management of mechanical NP, there was moderate evidence to support the application of neck strengthening and stretching exercises to improve long-term function (222). An earlier review on the effectiveness of neck exercise alone concluded that there was strong evidence to support the efficacy of dynamic strengthening and proprioceptive neck specific exercises the general population (223).

Hypertrophy of the cervical musculature following an exercise intervention may translate to enhanced energy absorption capabilities, resulting in enhanced dynamic stabilization of the cervical spine during loading events (56, 221, 224). Mansell et al. (91) has suggested that the head-neck segment dynamic restraint system could theoretically provide protective properties similar to those documented in the knee and shoulder (225-227). Dynamic stabilization of a joint is dependent upon both feed-forward and feedback mechanisms to coordinate movement patterns in anticipation of and in reaction to movements or the application of a load (91). As previously highlighted, co-contraction of the sternocleidomastoid (SCM) and the trapezius muscle prior to the application of an impulse load has been shown to reduce head displacement and acceleration through feed-forward mechanisms (130, 153, 157, 158). The feedback mechanism of control relies on reactive muscle activation and uses neural reflex pathways to regulate movement (91). These reflex responses in the cervical region are regulated by sensory input received by the vestibular, visual and mechanoreceptors in the head and neck (158, 228). Hypertrophy of the cervical musculature has been documented in response to the implementation of a neck specific progressive resistance training program (39). More importantly, resistance training of this musculature may provide a functional stimulus to improve neuromuscular recruitment patterns and control (51), thereby increasing the rate and amount of muscle force development (91, 225). This improvement in the rate and amount of force development in muscles of the
Cervical spine may translate into potential protective mechanisms that diminish the severity or frequency of minor neck injuries.

These concepts have been examined in two neck exercise intervention studies in which the effects of cervical strength on head kinematics were examined during a dynamic stabilization task in football players (91) and during a tackle in American gridiron players (90). In the dynamic stabilization task, male and female football players were divided into either a resistance training or control group that were assessed before and after the intervention. The resistance training group incorporated neck specific exercises into their regular gym training routines 2 x per week for 8-weeks. After completion of the post-intervention assessment, the authors reported no reduction in head-neck segment acceleration in the resistance trained group despite an improvement in Flx peak force of the males. In addition, no changes in muscle onset times for the SCM or the upper trapezius were observed. The authors concluded that these findings indicate the need for “neck muscle training tasks that elicit feed-forward and feedback motor control mechanisms to better use dynamic stabilizers for both protection and performance enhancement” (91). Ballistic activities (plyometrics) have enhanced neuromuscular control and dynamic stabilization in other regions of the body (225-227).

In a similar study to Mansell et al. (91), the effects of an 8-week isoinertial cervical resistance training program on head and neck kinematics and neuromuscular activity of the SCM and upper trapezius were examined during an American gridiron tackle using EMG and a ViconNexus® 3D motion capture system. The intervention consisted of isoinertial Ext, Flx, RtFlx, and LtFlx at a resistance load of 60-80% of the 10RM for 3 sets of 10 reps 2-3 x per week. Post-intervention improvements were observed for Ext (7%) and LtFlx (10%); however, these changes failed to augment the neuromuscular response of the SCM or upper trapezius, peak linear or angular head acceleration during the tackling task (90). Consistent with the Mansell study, these authors’ proposed that the exercises in the intervention failed to emphasize hypertrophy, muscle contraction velocity and muscle co-contraction of the SCM and upper trapezius, which potentially explains the lack of statistically significant findings.

The majority of cervical injuries sustained in rugby are classified as minor in severity (30) encompassing nerve root injuries, ligament sprains, muscle strains, soft tissue
contusions to spinal nerve pathologies (i.e., nerve traction injuries, disc protrusions, joint pathologies) (54, 55, 230). Forces and constraints imposed on cervical motion during contact events (tackling and scrummaging) during rugby have been linked with early degenerative and arthritic lesions (47, 83, 98, 235). In addition to these arthritic symptoms, research examining the long-term impacts of this degeneration have observed neuroforaminal narrowing and predisposition to nerve root or spinal nerve pathologies in the affected individuals (233). To minimize or mitigate the symptoms of these pathologies, a number of authors have recommended the inclusion of general cervical muscle strengthening exercises in the normal training routine for athletes in collision based sports (53, 54, 233). Specifically, Cross et al. (54) state that “the incorporation of such exercises may be of great benefit as preventative measures against hypermobility of spinal segments and violent excursions of the cervical spine, which may lead to a non-catastrophic injury to the cervical spine”. In addition, neck exercises have been recommended for tensile injuries (stingers) to the cervical regions, with a rehabilitation strategy focused on cervicothoracic stabilization (232, 233).

In rugby the majority of evidence surrounding the use of neck specific interventions is limited to position papers (56, 57, 234), or a single case study (88). Recently, a two year retrospective analysis was conducted examining the effectiveness of a 26-week isometric neck specific intervention on reducing the number and severity of cervical spine injuries in a professional Rugby Union squad (73). The intervention consisted of two 13-week mesocycles, the first mesocycle focused on strengthening, the second mesocycle progressed participants into a maintenance phase. The selection of neck specific isometric exercises ranged from non-specific to position specific exercises which incorporated different body and upper limb positions. No changes in the total number of neck injuries sustained or time lost over the season due to neck injuries were observed. However, further analysis into the occurrence of these injuries revealed a decrease in the number of match injuries sustained with 11 reported in 2007-08 and two in 2008-09 (73). These findings suggest that the implementation of a neck specific intervention may provide a feasible prevention strategy to minimize or mitigate the occurrence of neck injuries.
7.2 Research Questions

The primary aim of this study was to examine the effectiveness of a neck specific exercise intervention in a professional rugby team. As the situation did not allow for the recruitment of a matched control group who would be available for testing over the same period of time, a non-matched (temporally) group of professional rugby players (control group) were used as a point of comparison. In order to examine the effectiveness of the neck exercise intervention, pre- and post-season neck strength and endurance measurements were conducted. In addition to measures of neuromuscular function, changes in current, average, and worst NP and NS were also monitored pre- and post-season. For the strength and endurances measures, relative and absolute reliability values were calculated to determine whether improvements or decrements in performance had occurred over the season in the two groups.

The secondary aim of this study was to explore the effect training adherence had on those in the neck exercise intervention group. If the cervical musculature plays a role in injury prevention, it is essential to monitor the functional capacity of these muscles in order to observe improvements or decrements resulting from exposure to a neck specific exercise intervention relative to a control group.

7.3 Methods

7.3.1 Research design

This study was a prospective, longitudinal examination of the effectiveness of a neck specific exercise intervention in a team of professional rugby players using pre- and post-season peak force and submaximal endurance measure in Ext, Flx, LtFlx and RtFlx. In addition to these strength and endurance variables the functional success of the program was appraised using current, average and worst NP and NS reported on a visual analogue scale (VAS). The pre- and post-season values obtained in the intervention group were compared to the same examined parameters in a control team that was recruited and did not receive the intervention.

Due to restricted researcher access to professional rugby athletes, a true control group of participants was not possible. The non-intervention group consisted of a team of players from the same competition who were only able to be initially tested at the end
of the season (post-season year 1) and subsequently before the start of the next season (pre-season year 2). Any learning effects (test 1 vs test 2) and the effect of a season of play (pre-season vs post-season) were explored.

Based on previous experience implementing interventions and shifts in training priorities as the season progressed, the intervention group was blocked into high (HA) and low adherers (LA) based on the average adherence during the regular season. The secondary aim of this study was to evaluate the impact training adherence had on the examined neuromuscular variables and measures of functional success.

7.3.2 Ethics

Institutional ethical approval was obtained from the University of Otago Human Ethics Committee (Appendix K) and the Ngāi Tahu Research Consultation Committee (Appendix L). Informed consent was provided by all participants (Appendix M).

7.3.3 Participants

Potential teams were approached about participating through direct contact with the team medical doctor, physiotherapist or from a referral by a representative of the New Zealand Rugby Union national team. Participants were recruited on a volunteer basis from two Super 15 teams. Due to the geographic location of the two teams, one team based in the same city as the research institute received the neck specific intervention program (NG, n= 29) while the other team located a considerable distance away was asked to continue their normal training routine and functioned as a comparison group (CON, n= 27).

All participants were at the time playing professional Super 15 rugby. Participants were excluded if they were not currently playing rugby at a Super 15 level for the two recruited teams. The voluntary nature of the project and the confidentiality of the outcomes and medical information were emphasized to all participants.

7.3.4 Rugby season

The study consisted of a pre-season assessment that was conducted during the first week of the pre-season and a post-season assessment that was conducted at the end of the regular season. The 2012 rugby season consisted of a 10 week pre-season and a 21
week regular season with 16 regular season games. As the CON team was not recruited until half way through the 2012 season, pre-season testing was conducted at the start of the 2013 season. Refer to the figure below for a visual illustration of the testing schedule (Figure 7.1).

![Figure 7.1: Timing of pre- and post-season assessments for the neck intervention (NG) and the control group (CON) relative to the Super 15 2012 and 2013 seasons.](image)

### 7.3.5 Testing apparatus

A custom built device was designed to assess participants in a simulated contact posture that is a functionally relevant body position for collision sports such as rugby. The apparatus included: (a) an adjustable padded support bench, (b) adjustable forearm bench, and (c) a vertical pole mount with a headpiece (Figure 4.2). A detailed description of the apparatus is provided in Chapter 4: Part I. All equipment settings for each individual were recorded to standardize the body position between the pre- and post-season assessments.

### 7.3.6 Experimental protocol

The candidate conducted all assessments at approximately the same time of day. During the first initial session, all participants’ body mass (kg), stature (cm) and neck circumference (cm) were measured. Participants were then asked to fill out a questionnaire relating to their rugby career: playing position, number of years played at Super 15 level, total number of years of rugby played, handedness, whether they completed neck specific exercises and tackle shoulder preference (Appendix N). Prior to any strength measurements, participants were asked to rate their current levels of NP and NS, and average and worst levels over the previous three weeks using a 100mm VAS (6, 284). Neck circumference, NP and NS were measured and the warm-up
performed following the same protocol outlined in Part I Section 4.4.4. This process was conducted for both the pre- and post-season assessments.

**Peak force assessment.** Once positioned in the testing apparatus, the relaxed weight of the head on the four force transducers was recorded. To account for the weight of the head or the pressure on the force transducers in a neutral position, these values were subtracted from the maximal values achieved for each direction. Immediately preceding data collection, participants were familiarized with the apparatus and tasks by performing two or three submaximal contractions and then a single unrecorded maximal voluntary contraction (MVC) in each tested direction. A single isometric MVC was then performed for Ext, Flx, LtFlx and RtFlx in a randomly determined order that varied for each participant. Instructions regarding the performance of each MVC were conducted as described in Chapter 4 Part I Section 4.4.4. The maximum force achieved during the 5 s was recorded as the MVC in Newtons (N).

**Submaximal endurance assessment.** Participants performed a single submaximal endurance trial for all four directions following the same testing order as the peak force assessment. Instructions regarding the performance of each submaximal endurance trial and protocol were conducted as described in Chapter 4 Part I Section 4.10.4.

**Endurance trial data processing.** Endurance trials were analysed to determine the area under the force curve (AUC) and the time to fatigue (TTF) for all four directions (Ext, Flx, LtFlx and RtFlx). The AUC was used as an index of cervical muscle fatigue during each endurance trial and was calculated using MATLAB (MathWorks®, Natick, MA) employing the trapezium rule method. The MVC peak forces recorded during the pre-season assessment were used to calculate the 70% and 90% MVC target forces for the post-season endurance trials. This recording allowed for direct comparisons between the pre- and post-season assessment periods to determine whether changes in endurance performance had occurred. The description and calculation of %AUC and TTF values is provided in Chapter 4 Part II Section 4.10.4.

### 7.3.7 Neck specific exercise intervention program

Each neck intervention session consisted of four key components that alternated depending on the timing of the session during the week relative to the game, playing
Chapter 7 – Neck Exercise Invention

position and/or the specific needs of the player. The key components of the neck intervention were the following:

1. Muscle coordination focusing on the deep cervical stabilizers;
2. Neck muscle endurance through a dynamic range of motion;
3. Isometric strength in a neutral position;
4. Impulsive loading using low level resistance in a neutral neck position.

The neck intervention programme was implemented at the start of the pre-season during each gym session as part of their regular resistance training routine (2-3 x per wk for 10wks). Each neck intervention session lasted for 10-15 min for the players who volunteered to participate in the study in addition to their regular training routine. During the regular season, the neck intervention sessions were no longer implemented as part of their regular resistance training routines, rather players were given the option to attend. In the regular season the neck intervention sessions were offered 1-2 x per week and were 5-15 min in length depending on the player’s specific needs. All intervention sessions were supervised by the candidate and participants were given continual feedback with regards to exercise performance and posture (6, 72). Refer to Chapter 6 for a description of the four different components of the intervention and the exercises that were performed. A comprehensive version of the neck specific exercise program is provided in the appended CD at the back of the thesis.

7.3.8 Statistical analyses

Descriptive statistics (mean and SD) were calculated for the anthropometric variables, MVC, %AUC and TTF for each direction (Ext, Flx, LtFlx and RtFlx) and session (pre- and post-season). Figure 5.2 provides a detailed outline of the statistical processes used to guide the analysis. Previous research examining peak force has highlighted the importance of data normalization between strength measures and anthropometric variables to enable comparisons of strength between individuals (4). For the purpose of this study, the term normalization refers to the adjustment of the examined physiological measure (peak force or endurance) to control for the contribution of body size (age, height, weight, neck girth) to the overall variation in the data (4). Pearson’s product-moment correlations were calculated to initially explore the relationship between the peak force and endurance measures and the continuous anthropometric
variables: age, weight, height and neck girth (75, 289). As previous research has demonstrated an increase in degenerative changes in the cervical spine of professional rugby players as their careers progress, number of minutes played over the season, years of Super 15 played and total number of years of rugby played were also included in the correlation analysis.

To determine whether it was necessary to control for variations in body size among the two groups (NG and CON), each anthropometric variable was assessed using a mixed model ANCOVA to develop predictive models for the entire sample as a whole (4). If none of the anthropometric variables contributed to variance in the models for peak force or endurance, analysis was continued using the raw data. However, if a variable contributed to the variance in the model, a formulae was developed to normalize the respective strength and/or endurance measures to account for the variability due to the differences in that anthropometric variable (4). The basis for deriving these normalized values was centred on the strong relationship between anthropometric variables such as body weight and peak force (4, 289).

To explore whether the season or the timing of the assessments had a bigger impact on the examined variables the 2012 pre-season (session 1) values for the NG were compared to the 2012 post-season (session 1) and 2013 pre-season (session 2) results for the CON using independent t-tests. If Levene’s test for equality of variance were significant equal variances were not assumed and the degrees of freedom were adjusted.

A 3(group) x 2(time) mixed model ANOVA was then conducted on the raw endurance and the normalized peak force data. Where appropriate, Bonferroni comparisons were used to explore the statistically significant main effects for group and time. For statistically significant interactions, visual inspection of the mean MVC, TTF and the %AUC values for the pre- and post-season assessments for all four directions were conducted using methods described by Jaccard and Guilamo-Ramos (290). Single degree-of-freedom contrasts (dependent t-tests) were used to examine if statistically significant changes in the HA, LA, NG and CON had occurred (290). Statistical significance for the interaction and single degree of freedom contrast were determined using a directional α level of 0.05.
To determine the relative reliability of the device and testing procedures, average and single measure Intra-class Correlation Coefficients (ICC\(_{2,1}\)) and 95% confidence intervals (95% CI) were calculated using the MVC values from the pre- and post-season assessments for each direction. The ICC were evaluated using the following criteria: poor ICC < 0.50, moderate 0.50 ≤ ICC < 0.70, good 0.70 ≤ ICC < 0.90, and excellent ICC ≥ 0.90 (163).

Absolute reliability was determined using the measurement error associated with a single MVC measurement, calculated as the SEM using the following formula: SEM = \(SD \times \sqrt{1 - ICC}\) (286). The \(SD\) value used was the average \(SD\) of the pre- and post-season combined and the ICC value was the 2-way random model single measure consistency value. This ICC value was chosen because it is a reflection of the error associated with a measurement collected at a single point in time (286). The %SEM was calculated using the average mean peak force (291). The error associated with multiple measures of maximum strength for each direction was calculated as the minimal detectable change (MDC). The MDC is the smallest amount of change in the MVC scores that can be considered actual change that exceeds error in the measurement. It was determined using the following formula: MDC = 1.96 x \(\sqrt{2 \times SEM}\) and was calculated to the 95% confidence level (287).

For the current, average and worst NP and NS VAS values, a difference score was calculated. Following this calculation, a one-way ANOVA was run for each VAS score with a Tukey’s post-hoc comparison to evaluate group differences. SPSS 19.0 (IBM SPSS Statistics, Somers, N.Y.) was used for all statistical analyses, and the criteria for statistical significance was set at \(\alpha= 0.05\).

### 7.4 Results

#### 7.4.1 Participants

Fifty-six participants (32 F, 24 B) were recruited from two Super 15 teams (NG: \(n = 29\) and CON: \(n = 27\)). Due to scheduling conflicts, international team commitments and the occurrence of injuries during the season, only 42 participants completed both the pre- and post-season assessments (NG: \(n = 27\); 16 F + 11 B and CON: \(n = 15\); 11 F + 4 B). Anthropometric values are reported in Table 7.1 by NG and CON groups for the 56
participants who completed the single session and the subset of the 56 (n= 42) who completed both sessions. Independent t-tests comparing anthropometric characteristics and career related information between the NG and CON participants who completed the single testing and NG and CON participants who completed both testings found no differences between the NG and CON groups (p > 0.05).
Table 7.1: Anthropometric characteristics of the neck intervention (NG) and the control group (CON) for those that completed only a single testing session and those that completed both sessions

<table>
<thead>
<tr>
<th>Measured variable</th>
<th>Single session (n= 56)</th>
<th>Both sessions (n= 42)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Mean</td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>NG</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>27</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>NG</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>27</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>NG</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>27</td>
</tr>
<tr>
<td>Neck girth pre (cm)</td>
<td>NG</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>15</td>
</tr>
<tr>
<td>Neck girth post (cm)</td>
<td>NG</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>27</td>
</tr>
<tr>
<td>Min played 2012 season</td>
<td>NG</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>27</td>
</tr>
<tr>
<td># of yrs Super 15</td>
<td>NG</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>27</td>
</tr>
<tr>
<td># yrs rugby total</td>
<td>NG</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>27</td>
</tr>
</tbody>
</table>

7.4.2 Neck intervention group vs controls

As the temporal pattern of session 1 for the NG and the CON did not align due to circumstances beyond the control of the researcher, session 1 for the NG (2012 pre-season) was compared to the CON session 1 (2012 post-season) and session 2 (2013 pre-season). The peak force results for the independent t-test for session 1 for NG and the CON revealed a statistically significant difference for Ext, $t_{(40)}= 2.24$, $p= 0.03$, LtFlx, $t_{(40)}= 3.57$, $p< 0.01$, and RtFlx, $t_{(40)}= 2.53$, $p= 0.02$. In contrast, when the pre-season values for the two teams were compared, no differences were isolated for any of the four examined directions. For the endurance variables when the session 1 values were examined, a statistically significant difference for RtFlx was isolated for %AUC, $t_{(16.18)}= 2.62$, $p= 0.02$, and TTF, $t_{(16.34)}= 2.65$, $p= 0.02$. The pre-season values for the NG and the CON revealed that LtFlx was statistically significant for both %AUC, $t_{(17.44)}= 3.21$, $p= 0.01$, and TTF, $t_{(17.32)}= 3.36$, $p< 0.01$. The same pattern was also observed for
the pre-season RtFlx values with statistically significant results for %AUC, \( t_{15.64} = 3.26, p = 0.01 \), and TTF, \( t_{15.88} = 3.37, p < 0.01 \). The session 1 NP and NS values for the two teams indicated a statistically significant difference for current NP, \( t_{40} = 2.15, p = 0.04 \), worst NP, \( t_{40} = 3.65, p < 0.01 \), and worst NS, \( t_{40} = 2.24, p = 0.03 \). No statistical differences were observed for the pre-season NP or NS scores between the two groups. Based on the larger proportion of statistically significant differences between the NG and the CON during the session 1 assessment, we elected to compare the two teams using the pre- and post-season data.

### 7.4.3 Neck intervention training adherence

During the 10 week pre-season, mean training adherence was 85.23 ± 4.67%. During the 21 week regular season, training attendance dropped to 25.37 ± 14.78% with a minimum attendance rate of 9.43% and a maximum of 71.70%. To compare the effectiveness of the neck exercise program, the intervention group was dichotomized into two groups using the mean in-season attendance of 25.37%: LA (<25.37%; \( n = 16 \)) and HA (≥25.37%; \( n = 11 \)).

### 7.4.4 Peak force

#### 7.4.4.1 Peak force normalization

To determine whether peak force was correlated to any anthropometric or rugby career variable, Pearson’s product moment correlations were conducted (see Table 7.2) (75). During the pre-season, weight and neck girth were both correlated to peak force values in all four directions (\( p < 0.01 \)). Post-season weight was only correlated to Ext peak force, while neck girth correlated to both Ext and Flx (\( p < 0.01 \)).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Pre-season peak force</th>
<th>Post-season peak force</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ext</td>
<td>Flx</td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>( r )</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>( p )</td>
<td>0.79</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>( r )</td>
<td>0.20</td>
</tr>
</tbody>
</table>
A single mixed model ANCOVA was then conducted for each of the strength variables using the anthropometric and career information variables as covariates to develop predictive models (4). The ANCOVA results revealed that only neck girth was found to contribute to the variance. The resulting models were utilized to develop formulas that were used to normalize the respective strength variables and to account for the variability due to differences in neck girth.

### 7.4.4.2 Neck intervention group vs controls

The raw peak force values recorded during the pre- and post-season assessment in both the NG and CON are presented in Figure 7.2. To compare these normalized peak force values for the NG and CON across the season, a 2(group) x 2(time) mixed model ANOVA was conducted. For Ext and LtFlx, a statistically significant main effect for time was observed, indicating a difference in these peak force values between the pre- and post-season assessments for both groups. For the group main effect, statistically significant results were achieved between the two groups for LtFlx and RtFlx, suggesting there was a difference in the peak force values between the two groups when collapsed across time. To compare the effect of the season and the intervention, interaction effects were examined. For all four directions, statistically significant interactions were revealed when comparing the pre- and post-season normalized peak
force values for the NG and CON (Table 7.3). When each group was examined independently, the NG normalized peak force values for Flx, LtFlx, and RtFlx improved over the season while Ext remained unchanged. The opposite trend was displayed by the CON where the pre-season values were higher than the post-season results for all four directions (Table 7.4).

![Figure 7.2: Raw peak force (N) values for the neck intervention group (NG) and the controls (CON) pre- and post-season for the four tested directions](image)

* Indicates statistical significance at the 0.05 level
### Table 7.3: The results for the normalized peak force (N) repeated measures analysis of variance and the single degree of freedom contrasts conducted during the pre- and post-season assessment for the neck intervention group (NG) and the control (CON)

<table>
<thead>
<tr>
<th></th>
<th>Main effect</th>
<th>Single degree of freedom contrasts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time</td>
<td>Group</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F(1, 40) p</td>
</tr>
<tr>
<td>MVC</td>
<td>Ext</td>
<td>11.06 .01*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Flx</td>
<td>0.47 .50</td>
</tr>
<tr>
<td></td>
<td>LtFlx</td>
<td>8.71 .01*</td>
</tr>
<tr>
<td></td>
<td>RtFlx</td>
<td>1.74 .19</td>
</tr>
</tbody>
</table>

* Indicates statistical significance at the 0.05 level

### Table 7.4: Normalized peak force (N) and absolute and relative reliability values for the neck intervention group (NG) and the controls (CON) pre- and post-season

<table>
<thead>
<tr>
<th>Direction</th>
<th>Group</th>
<th>Pre-season</th>
<th>Mean</th>
<th>SD</th>
<th>Post-season</th>
<th>Mean</th>
<th>SD</th>
<th>Δ</th>
<th>ICC(2,1)</th>
<th>95% CI</th>
<th>SEM</th>
<th>% SEM</th>
<th>MDC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extension</td>
<td>NG</td>
<td>413.23</td>
<td>75.74</td>
<td></td>
<td>403.37</td>
<td>77.11</td>
<td></td>
<td>-1.01</td>
<td>0.77</td>
<td>0.50-0.90</td>
<td>36.54</td>
<td>8.95</td>
<td>101.29</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>428.34</td>
<td>45.09</td>
<td></td>
<td>359.50</td>
<td>59.08</td>
<td></td>
<td>-7.02*</td>
<td>-0.33</td>
<td>-2.96-0.55</td>
<td>60.09</td>
<td>15.26</td>
<td>166.57</td>
</tr>
<tr>
<td>Flexion</td>
<td>NG</td>
<td>230.97</td>
<td>77.62</td>
<td></td>
<td>258.46</td>
<td>86.94</td>
<td></td>
<td>2.80*</td>
<td>0.80</td>
<td>0.56-0.91</td>
<td>36.74</td>
<td>15.01</td>
<td>101.84</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>242.81</td>
<td>48.21</td>
<td></td>
<td>202.39</td>
<td>58.56</td>
<td></td>
<td>-4.12*</td>
<td>0.93</td>
<td>0.79-0.98</td>
<td>14.17</td>
<td>6.37</td>
<td>39.27</td>
</tr>
<tr>
<td>LtFlx</td>
<td>NG</td>
<td>298.18</td>
<td>62.99</td>
<td></td>
<td>322.78</td>
<td>85.75</td>
<td></td>
<td>2.51*</td>
<td>0.75</td>
<td>0.54-0.90</td>
<td>37.31</td>
<td>12.02</td>
<td>103.41</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>312.30</td>
<td>39.94</td>
<td></td>
<td>225.59</td>
<td>59.26</td>
<td></td>
<td>-8.84*</td>
<td>0.64</td>
<td>-0.09-0.88</td>
<td>29.96</td>
<td>11.14</td>
<td>83.05</td>
</tr>
<tr>
<td>RtFlx</td>
<td>NG</td>
<td>289.01</td>
<td>78.33</td>
<td></td>
<td>322.46</td>
<td>95.14</td>
<td></td>
<td>3.41*</td>
<td>0.75</td>
<td>0.46-0.89</td>
<td>43.00</td>
<td>14.06</td>
<td>119.18</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>290.80</td>
<td>41.58</td>
<td></td>
<td>226.29</td>
<td>56.56</td>
<td></td>
<td>-6.58*</td>
<td>0.62</td>
<td>-0.14-0.87</td>
<td>30.34</td>
<td>11.73</td>
<td>84.09</td>
</tr>
</tbody>
</table>

* Indicates statistical significance at the 0.05 level
7.4.4.3 High vs low adherers

**Extension.** A 2(group) x 2(time) mixed model ANOVA for Ext revealed no main effects for time, $F_{(1,25)}= 0.01, p= 0.93$, or group, $F_{(1,25)}= 1.38, p= 0.25$. The improvement seen for the HA (26.59 N) was different from the decrease observed for the LA (-37.32 N), as indicated by the statistically significant interaction, $F_{(1,25)}= 5.84, p= 0.02$. The single degree of freedom contrast for the HA, $t_{(10)}= 2.00, p= 0.07$, was not statistically significant. Although the LA displayed a trend toward decreased Ext strength post-season, this trend was also not statistically significant, $t_{(15)}= 1.73, p= 0.10$ see Figure 7.3.

![Figure 7.3](image)

**Figure 7.3:** Raw peak force (N) values for the low and high adherers pre- and post-season for the four measured directions expressed as means and standard deviations

* Indicates statistical significance at the 0.05 level

**Flexion.** Examination of the Flx peak force results for the HA and LA revealed a main effect for time, $F_{(1,25)}= 7.39, p= 0.01$, indicating an improvement from pre- to post-season assessment. The statistically significant interaction, $F_{(1,25)}= 4.22, p= 0.05$, revealed a difference in the response between the LA and HA; however the main effect for group was not statistically significant, $F_{(1,25)}= 1.88, p= 0.18$. Further analysis of the statistically
significant interaction using single degree of freedom contrast illustrated that the LA remained unchanged, \( t_{(15)} = 0.75, p = 0.47 \), while the HA improved post-season, \( t_{(10)} = 2.33, p = 0.04 \).

**Left lateral flexion.** For LtFlx, a statistically significant main effect was isolated for time, \( F_{(1,25)} = 7.39, p = 0.01 \), and a trend towards statistical significance was seen for the group main effect, \( F_{(1,25)} = 3.96, p = 0.06 \). Despite the improvement observed for the HA over the season, \( t_{(10)} = 2.55, p = 0.03 \), the LA remained unchanged, \( t_{(15)} = 1.37, p = 0.19 \). Thus, the time by group interaction for the HA and LA was not statistically significant, \( F_{(1,25)} = 2.15, p = 0.16 \).

**Right lateral flexion.** The main effect for time, \( F_{(1,24)} = 8.02, p = 0.01 \), was the only statistically significant result for RtFlx. Both the group main effect, \( F_{(1,24)} = 1.39, p = 0.25 \), and the interaction, \( F_{(1,24)} = 3.65, p = 0.07 \), were not statistically significant. Similar to LtFlx when collapsed across groups, there was an improvement from pre- to post-season. Further examination of the improvement with respect to training attendance revealed a statistically significant improvement for the HA, \( t_{(10)} = 3.47, p = 0.01 \), which was the largest improvement seen for the four directions. The LA RtFlx strength remained unchanged, \( t_{(14)} = 0.68, p = 0.51 \).

**7.4.5 Endurance normalization**

To determine whether %AUC or TTF were correlated to any anthropometric or rugby career variable, Pearson’s product moment correlations were conducted see **Table 7.5** (75). None of the anthropometric or rugby career related variables demonstrated a strong correlation across the four examined directions, indicating that normalization of the raw endurance values was not necessary.
Table 7.5.: Pearson’s product-moment correlations values for the percent area under the force curve (%AUC) and time to fatigue (s) for the four measured directions and the continuous anthropometric variables measured pre-season (n= 42)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Pre-season % AUC</th>
<th>Pre-season time to fatigue (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ext</td>
<td>Flx</td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>0.12</td>
<td>-0.08</td>
</tr>
<tr>
<td></td>
<td>0.46</td>
<td>0.63</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>0.13</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>0.42</td>
<td>0.36</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>0.29</td>
<td>0.58</td>
</tr>
<tr>
<td></td>
<td>0.17</td>
<td>0.09</td>
</tr>
<tr>
<td>Pre-neck girth (cm)</td>
<td>0.17</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>0.88</td>
</tr>
<tr>
<td>Post-neck girth (cm)</td>
<td>0.17</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>0.29</td>
<td>0.99</td>
</tr>
<tr>
<td>Min played 2012 season</td>
<td>0.00</td>
<td>-0.04</td>
</tr>
<tr>
<td></td>
<td>0.01</td>
<td>-0.05</td>
</tr>
<tr>
<td></td>
<td>0.93</td>
<td>0.76</td>
</tr>
<tr>
<td># of yrs super 15</td>
<td>0.00</td>
<td>-0.05</td>
</tr>
<tr>
<td></td>
<td>0.01</td>
<td>-0.05</td>
</tr>
<tr>
<td># yrs rugby total</td>
<td>0.00</td>
<td>-0.05</td>
</tr>
<tr>
<td></td>
<td>0.01</td>
<td>-0.05</td>
</tr>
<tr>
<td></td>
<td>0.93</td>
<td>0.76</td>
</tr>
<tr>
<td># yrs rugby total</td>
<td>0.20</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>0.24</td>
<td>0.60</td>
</tr>
</tbody>
</table>

* Indicates statistically significant correlation, \( p < 0.05 \)

7.4.6 % Area under the curve

7.4.6.1 Neck intervention group vs controls

The raw %AUC data for both assessments is presented in Figure 7.4. To determine whether the intervention improved endurance capacity of the cervical musculature for the NG, the AUC for the submaximal endurance trials were analysed. As the 70% and 90% force requirements for the endurance trials were determined using each participant’s MVC, the AUC values were normalized to the individual’s respective MVC for each direction generating a %AUC value. For the Ext and Flx directions, no changes were observed over the season for the main effects for time, group, or the time x group interaction as displayed in Table 7.6 \( (p\)-values ranged from 0.06-0.78). Given the large standard deviation in the %AUC values for these two directions, it is not surprisingly there were no statistically significant changes for the NG and CON when examined independently from the pre-season to the post-season assessment (see Table 7.7; \( p\)-values ranged from 0.14-0.63).
For the LtFlx and RtFlx directions, no differences were observed for the NG and CON for the main effect for time. However, statistically significant group main effects and an interaction contrast were achieved over the season, indicating that the muscular endurance response for LtFlx and RtFlx varied for the NG and CON. When these statistically significant interactions were explored further using single degree of freedom contrast, it was revealed that for LtFlx over the season the CON endurance capacity decreased (-24.65 %AUC), while the NG remained unchanged (10.21 %AUC). For RtFlx, the opposite pattern was observed where the NG endurance capacity increased (27.48 %AUC) contrasted against the CON who remained unchanged (-13.26 %AUC), see Table 7.7.

Figure 7.4: Percent area under the force curve values (%AUC) for the neck intervention group (NG) and the controls (CON) pre- and post-season for the four tested directions
* Indicates statistical significance at the 0.05 level
Table 7.6: The results for the % AUC repeated measures analysis of variance and the single degree of freedom contrasts conducted during the pre- and post-season assessment for the neck intervention group (NG) and the controls (CON)

<table>
<thead>
<tr>
<th>Main effect</th>
<th>Time</th>
<th>Group</th>
<th>Interaction effect</th>
<th>Single degree of freedom contrasts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ext</td>
<td>Group</td>
<td></td>
<td>NG</td>
</tr>
<tr>
<td></td>
<td>F(1,40)</td>
<td>p</td>
<td>F(1,40)</td>
<td>p</td>
</tr>
<tr>
<td>%AUC</td>
<td>2.39</td>
<td>.13</td>
<td>1.05</td>
<td>.31</td>
</tr>
<tr>
<td>Flx</td>
<td>0.08</td>
<td>.78</td>
<td>3.84</td>
<td>.06</td>
</tr>
<tr>
<td>LtFlx</td>
<td>1.02</td>
<td>.32</td>
<td>6.67</td>
<td>.01*</td>
</tr>
<tr>
<td>RtFlx</td>
<td>0.71</td>
<td>.41</td>
<td>6.08</td>
<td>.02*</td>
</tr>
</tbody>
</table>

* Indicates statistical significance at the 0.05 level

Table 7.7: % AUC and absolute and relative reliability values for the neck intervention group (NG) and the controls (CON) pre- and post-season

<table>
<thead>
<tr>
<th>Direction</th>
<th>Group</th>
<th>Pre-season</th>
<th>Post-season</th>
<th>Δ</th>
<th>ICC(2,1)</th>
<th>95% CI</th>
<th>SEM</th>
<th>MDC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extension</td>
<td>NG</td>
<td>33.97</td>
<td>25.97</td>
<td>32.02</td>
<td>22.36</td>
<td>-1.95</td>
<td>0.78</td>
<td>0.51-0.90</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>46.85</td>
<td>40.56</td>
<td>35.73</td>
<td>27.93</td>
<td>-11.12</td>
<td>0.68</td>
<td>0.05-0.89</td>
</tr>
<tr>
<td>Flexion</td>
<td>NG</td>
<td>40.40</td>
<td>21.79</td>
<td>48.92</td>
<td>33.61</td>
<td>8.51</td>
<td>0.66</td>
<td>0.24-0.84</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>70.23</td>
<td>54.36</td>
<td>54.65</td>
<td>43.77</td>
<td>-15.58</td>
<td>0.40</td>
<td>-0.87-0.81</td>
</tr>
<tr>
<td>LtFlx</td>
<td>NG</td>
<td>49.12</td>
<td>27.92</td>
<td>59.33</td>
<td>41.36</td>
<td>10.21</td>
<td>0.43</td>
<td>-0.24-0.74</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>94.80</td>
<td>49.32</td>
<td>70.15</td>
<td>41.91</td>
<td>-24.65*</td>
<td>0.84</td>
<td>0.52-0.95</td>
</tr>
<tr>
<td>RtFlx</td>
<td>NG</td>
<td>37.88</td>
<td>16.87</td>
<td>65.37</td>
<td>47.72</td>
<td>27.49*</td>
<td>0.31</td>
<td>-0.54-0.69</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>83.00</td>
<td>52.16</td>
<td>69.74</td>
<td>45.37</td>
<td>-13.26</td>
<td>0.22</td>
<td>-1.31-0.74</td>
</tr>
</tbody>
</table>

* Indicates statistical significance at the 0.05 level
7.4.6.2 High vs low adherers

**Extension.** A 2(group) x 2(time) mixed model ANOVA for Ext revealed a statistically non-significant main effect for time, $F_{(1,25)} = 0.12$, $p = 0.73$, and statistically non-significant interaction, $F_{(1,25)} = 0.47$, $p = 0.50$ (**Figure 7.5**). While it appears that the LA and HA responded differently post-season, the main effect for group was not statistically significant, $F_{(1,25)} = 3.21$, $p = 0.08$. As the variability in this measure was large, no change in the %AUC were observed for either group using the single degree of freedom contrasts pre- to post-season.

![Figure 7.5: Percent area under the force curve values (%AUC) for the low and high adherers pre- and post-season for the four measured directions. * Indicates statistical significance at the 0.05 level](image)

**Flexion.** Consistent with the pattern observed in Ext, the Flx main effect for time, $F_{(1,25)} = 2.69$, $p = 0.11$, and the interaction of time by group, $F_{(1,25)} = 0.55$, $p = 0.46$, were not significant. The main effect for group was statistically significant, $F_{(1,25)} = 4.91$, $p = 0.04$, indicating that the HA produce larger %AUC values when collapsed across time. There was
no improvement in the Flx %AUC values for either the HA, $t_{(10)}= 1.37$, $p= 0.20$, or LA, $t_{(15)}= 0.83$, $p= 0.42$.

**Left lateral flexion.** For LtFlx, a statistically non-significant main effect was isolated for both time, $F_{(1,25)}= 3.25$, $p= 0.08$, and group, $F_{(1,25)}= 2.13$, $p= 0.16$. The decrease observed for the LA (-3.14 %AUC) differed from the improvement recorded by the HA (19.26 %AUC), as indicated by the statistically significant interaction, $F_{(1,25)}= 6.13$, $p=0.02$. Despite the statistically significant interaction, the 30.53 %AUC improvement seen in the HA, $t_{(10)}= 2.02$, $p= 0.07$, was not statistically significant. The small 3.14%AUC decrease over the season recorded by the LA also was not statistically significant, $t_{(15)}= 0.83$, $p= 0.42$.

**Right lateral flexion.** The main effect for time, $F_{(1,24)}= 10.41$, $p< 0.01$, was the only statistically significant result for RtFlx, indicating an improvement in RtFlx %AUC values for both groups. In contrast, both the group main effect, $F_{(1,24)}= 3.06$, $p= 0.09$, and the interaction of time by group, $F_{(1,24)}= 2.68$, $p= 0.11$, were not statistically significant. Further examination of the improvement with respect to training attendance revealed a statistically significant improvement for the HA, $t_{(10)}= 2.59$, $p= 0.03$, which was the largest improvement seen for the four directions. The LA RtFlx %AUC remained unchanged, $t_{(14)}= 1.85$, $p= 0.09$.

### 7.4.7 Time to fatigue

#### 7.4.7.1 Neck intervention group vs controls

To compare submaximal endurance trials for the pre- and post-season assessments between the NG and CON, the TTF for each direction were examined (**Figure 7.6**). For each direction, a 2(group) x 2(time) mixed model ANOVA for the TTF variables was conducted. For the Ext and Flx TTF values, no changes were observed over the season for the main effects for time or group, or the time by group interaction see **Table 7.8** ($p$-values ranged from 0.06-0.82). Given the large standard deviation in the TTF values for these two directions, it is not surprisingly there were no statistically significant changes for the NG and CON when examined over the season, as illustrated by **Table 7.9** ($p$-values ranged from 0.14-0.63).

For the LtFlx and RtFlx directions, no differences were observed for the study cohort over time. However, a statistically significant main effect for group, and time by group interaction were achieved over the season, indicating that the muscular endurance response between the
NG and CON for LtFlx and RtFlx varied. When the time by group interactions were explored further using single degree of freedom contrasts, TTF for LtFlx for the CON decreased by 19.95 s over the season, while the NG remained unchanged (8.52 s). For RtFlx, the opposite pattern was observed where the NG TTF increased by 22.28 s and the CON remained unchanged (-10.71 s).

**Figure 7.6:** Time to fatigue (seconds) values for the neck intervention group (NG) and the controls (CON) pre- and post-season for the four tested directions
* Indicates statistical significance at the 0.05 level
### Table 7.8: The results for the time to fatigue (s) repeated measures analysis of variance and the single degree of freedom contrasts conducted during the pre- and post-season assessment for the neck intervention group (NG) and the controls (CON)

<table>
<thead>
<tr>
<th></th>
<th>Main effect</th>
<th>Single degree of freedom contrasts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time</td>
<td>Group</td>
</tr>
<tr>
<td></td>
<td>$F_{(1, 40)}$</td>
<td>$p$</td>
</tr>
<tr>
<td>TTF Ext</td>
<td>2.41</td>
<td>.13</td>
</tr>
<tr>
<td>Flx</td>
<td>0.06</td>
<td>.82</td>
</tr>
<tr>
<td>LtFlx</td>
<td>1.06</td>
<td>.31</td>
</tr>
<tr>
<td>RtFlx</td>
<td>0.76</td>
<td>.39</td>
</tr>
</tbody>
</table>

* Indicates statistical significance at the 0.05 level

### Table 7.9: Time to fatigue (seconds) and absolute and relative reliability values for the neck intervention group (NG) and the controls (CON) pre- and post-season

<table>
<thead>
<tr>
<th>Direction</th>
<th>Group</th>
<th>Pre-season</th>
<th></th>
<th>Post-season</th>
<th></th>
<th>Δ</th>
<th>ICC&lt;sub&gt;(2,1)&lt;/sub&gt;</th>
<th>95% CI</th>
<th>SEM</th>
<th>MDC</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extension</td>
<td>NG</td>
<td>30.08</td>
<td>20.90</td>
<td>29.37</td>
<td>17.46</td>
<td>-0.71</td>
<td>0.78</td>
<td>0.59-0.90</td>
<td>8.98</td>
<td>24.90</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>42.04</td>
<td>32.61</td>
<td>32.41</td>
<td>22.14</td>
<td>-9.62</td>
<td>0.70</td>
<td>0.09-0.90</td>
<td>15.11</td>
<td>41.88</td>
</tr>
<tr>
<td>Flexion</td>
<td>NG</td>
<td>34.95</td>
<td>17.39</td>
<td>42.27</td>
<td>27.01</td>
<td>7.32</td>
<td>0.65</td>
<td>-0.16-0.76</td>
<td>13.19</td>
<td>36.55</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>59.00</td>
<td>42.78</td>
<td>46.58</td>
<td>35.45</td>
<td>-12.42</td>
<td>0.38</td>
<td>-0.60-0.82</td>
<td>30.85</td>
<td>85.53</td>
</tr>
<tr>
<td>LtFlx</td>
<td>NG</td>
<td>42.41</td>
<td>21.75</td>
<td>50.93</td>
<td>32.09</td>
<td>8.52</td>
<td>0.44</td>
<td>0.49-0.90</td>
<td>20.08</td>
<td>55.66</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>80.08</td>
<td>38.94</td>
<td>60.13</td>
<td>33.64</td>
<td>-19.95*</td>
<td>0.84</td>
<td>0.40-0.93</td>
<td>14.58</td>
<td>40.42</td>
</tr>
<tr>
<td>RtFlx</td>
<td>NG</td>
<td>33.27</td>
<td>14.11</td>
<td>55.56</td>
<td>36.83</td>
<td>22.28*</td>
<td>0.31</td>
<td>0.59-0.92</td>
<td>21.15</td>
<td>58.61</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>70.03</td>
<td>40.88</td>
<td>59.33</td>
<td>36.64</td>
<td>-10.71</td>
<td>0.23</td>
<td>-1.28-0.74</td>
<td>33.92</td>
<td>94.02</td>
</tr>
</tbody>
</table>

* Indicates statistical significance at the 0.05 level
7.4.7.2 High vs low adherers

**Extension.** A 2(group) x 2(time) mixed model ANOVA for Ext TTF revealed no main effects for time, $F_{(1,25)}=0.02$, $p=0.90$, or group, $F_{(1,25)}=3.01$, $p=0.09$. The time by group interaction between the LA and HA was also not statistically significant, $F_{(1,25)}=0.22$, $p=0.64$. As the variability in this measure was quite large, no changes in the TTF were found for either group using the single degree of freedom contrasts pre- to post-season (Figure 7.7).

**Figure 7.7:** Time to fatigue (s) for the high and low adherers pre- and post-season for the four measured directions
* Indicates statistical significance at the 0.05 level

**Flexion.** Consistent with the pattern observed in Ext, the Flx main effect for time, $F_{(1,25)}=2.99$, $p=0.09$, and the interaction of time by group, $F_{(1,25)}=0.51$, $p=0.48$, were not statistically significant. In contrast, the difference between the two groups when collapsed across time was statistically significant, $F_{(1,25)}=4.76$, $p=0.04$, reflecting the HA ability to sustain their submaximal endurance trials for a longer period of time. When the changes in the Flx TTF for the HA and LA across the season were examined, there were no improvement for either the HA, $t_{(10)}=1.41$, $p=0.19$, or LA, $t_{(15)}=0.88$, $p=0.39$. 

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**Left lateral flexion.** For LtFlx, a statistically non-significant main effect was isolated for both time, $F_{(1,25)} = 3.68$, $p = 0.07$, and group, $F_{(1,25)} = 2.05$, $p = 0.16$. The TTF decrease observed for the LA (-3.28 s) was different from the improvement recorded for the HA (25.37 s), reflecting the statistically significant interaction, $F_{(1,25)} = 6.26$, $p = 0.02$. Despite the interaction, the improvement from 42.37 s pre-season to 66.77 s post-season for the HA was not statistically significant, $t_{(10)} = 2.10$, $p = 0.06$. Consistent with previous directions, the small decrease from 42.07 s to 40.04 s over the season recorded by the LA was also was not statistically significant, $t_{(15)} = 0.71$, $p = 0.49$.

**Right lateral flexion.** The main effect for time, $F_{(1,24)} = 12.24$, $p < 0.01$, was the only statistically significant result for RtFlx, indicating an improvement in RtFlx TTF for both groups. In contrast, both the group main effect, $F_{(1,24)} = 2.99$, $p = 0.10$, and the interaction of group by time, $F_{(1,24)} = 2.26$, $p = 0.15$, were not statistically significant. Further examination of the improvement with respect to training attendance revealed a statistically significant improvement for the HA, $t_{(10)} = 2.62$, $p = 0.02$, from 33.00 s to 69.74 s, which was the largest improvement seen for the four directions. The LA remained unchanged over the season for RtFlx TTF, $t_{(14)} = 2.00$, $p = 0.06$.

### 7.4.8 Neck pain visual analogue scores

#### 7.4.8.1 Neck intervention group vs controls

One of the purposes of this study was to examine changes that occurred in self-reported NP in response to the implementation of a neck specific intervention relative to a control sample not exposed to the intervention. Comparison of pre-season NP results using independent t-tests revealed no differences in the NG and CON self-reported pain scores for current, average or worst NP. During the pre-season assessment, 50.00% of the NG reported having no NP; this value increased to 57.69% during the post-season assessment. For the CON, during the pre-season 73.33% of the individuals reported having no current NP and this value decreased to 20.00% post-season. Dependent t-test were conducted to explore the changes in NP over the season. For the NG, NP scores remained unchanged for current, $t_{(25)} = 0.77$, $p = 0.45$, average, $t_{(25)} = 0.38$, $p = 0.71$, and worst, $t_{(25)} = 0.34$, $p = 0.74$. For the CON, NP scores remained unchanged over the competitive season for current, $t_{(14)} = 1.55$, $p = 0.14$ and average, $t_{(14)} = 1.40$, $p = 0.18$; however, there was a statistically significant increase in worst NP over the season, $t_{(14)} = 2.18$, $p = 0.05$ (Figure 7.8).
To determine whether there was a difference in self-reported NP response between the NG and the CON, one-way ANOVAs were conducted on the difference scores for current, average and worst NP. No differences were observed for current, $F_{(1,39)} = 1.57$, $p = 0.22$, or average NP, $F_{(1,39)} = 2.64$, $p = 0.11$; however, differences between the NG and CON groups for worst NP were statistically significant, $F_{(1,39)} = 4.06$, $p = 0.05$, over the season (Table 7.10). This difference between the NG and CON was attributable to the increase in worst NP observed in the CON post-season.
Table 7.10: Pre- and post-season visual analogue scale scores (mm) for the neck intervention (NG) and control group (CON) for current, average and worst neck pain (NP) over the past 3 weeks

<table>
<thead>
<tr>
<th>Visual analogue scale (mm)</th>
<th>Group</th>
<th>Pre-season</th>
<th>Post-season</th>
<th>95% Confidence interval</th>
<th>95% Confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Current NP</td>
<td>NG</td>
<td>8.91</td>
<td>14.09</td>
<td>11.54</td>
<td>16.85</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>9.97</td>
<td>17.35</td>
<td>20.20</td>
<td>19.75</td>
</tr>
<tr>
<td>Avg NP</td>
<td>NG</td>
<td>12.15</td>
<td>15.13</td>
<td>11.52</td>
<td>15.77</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>6.50</td>
<td>13.41</td>
<td>15.17</td>
<td>16.01</td>
</tr>
<tr>
<td>Worst NP</td>
<td>NG</td>
<td>20.70</td>
<td>24.13</td>
<td>23.48</td>
<td>28.83</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>24.73</td>
<td>29.00</td>
<td>50.67</td>
<td>27.77</td>
</tr>
</tbody>
</table>

* Indicates statistical significance at the 0.05 level
### 7.4.8.2 High vs low adherers

One of the other purposes of this study was to examine changes that occurred in self-reported NP in response to the implementation of a neck specific intervention. During the pre-season assessment, 41.18% of the LA reported having no NP; this value increased to 50% during the post-season assessment. For the HA during the pre-season, 50.00% of the individuals reported having no current pain and this improved to 60.00% post-season (Table 7.11).

To normalize the NP values for individual variation in responses, difference scores were calculated using the pre- and post-season VAS scores. To determine whether there was a difference in self-reported NP response between the HA and LA, a one-way ANOVA was conducted for current, average and worst NP on the difference scores. No statistical differences were observed for current, $F_{(1,24)}=0.01, p=0.91$, average, $F_{(1,24)}=0.01, p=0.95$, or worst, $F_{(1,24)}= 1.71, p=0.20$, NP over the season (Figure 7.9). Dependent t-tests were then conducted to examine the changes in NP for each group over the season. For the HA, NP remained unchanged for current, $t_{(9)}= 0.48, p=0.64$, average, $t_{(9)}= 0.28, p=0.78$, and worst, $t_{(9)}= 1.08, p=0.31$, from the pre- to post-season assessment. Similar to the HA, the LA NP scores remained unchanged over the course of the intervention for all three VAS scales (current: $t_{(15)}= 0.58, p=0.57$; average: $t_{(15)}= 0.25, p=0.80$; worst: $t_{(15)}= 0.60, p=0.55$).

#### Table 7.11: Current, average and worst self-reported neck pain (NP) visual analogue scale scores (mm) for the low (LA) and high adherers (HA) pre- and post-season

<table>
<thead>
<tr>
<th>Visual analogue scores (mm)</th>
<th>Group</th>
<th>Pre</th>
<th>Mean</th>
<th>SD</th>
<th>Post</th>
<th>Mean</th>
<th>SD</th>
<th>Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current NP</td>
<td>LA</td>
<td>Mean</td>
<td>7.59</td>
<td>12.38</td>
<td>9.94</td>
<td>14.68</td>
<td>2.35</td>
<td></td>
</tr>
<tr>
<td></td>
<td>HA</td>
<td>Mean</td>
<td>9.46</td>
<td>15.97</td>
<td>14.10</td>
<td>20.44</td>
<td>4.64</td>
<td></td>
</tr>
<tr>
<td>Average NP</td>
<td>LA</td>
<td>Mean</td>
<td>12.35</td>
<td>14.37</td>
<td>12.00</td>
<td>16.64</td>
<td>-0.35</td>
<td></td>
</tr>
<tr>
<td></td>
<td>HA</td>
<td>Mean</td>
<td>10.08</td>
<td>16.03</td>
<td>10.75</td>
<td>15.12</td>
<td>0.67</td>
<td></td>
</tr>
<tr>
<td>Worst NP</td>
<td>LA</td>
<td>Mean</td>
<td>24.65</td>
<td>26.36</td>
<td>21.78</td>
<td>27.59</td>
<td>-2.87</td>
<td></td>
</tr>
<tr>
<td></td>
<td>HA</td>
<td>Mean</td>
<td>12.17</td>
<td>17.89</td>
<td>26.20</td>
<td>32.03</td>
<td>14.03</td>
<td></td>
</tr>
</tbody>
</table>

* Indicates statistical significance at the 0.05 level
Figure 7.9: Self-reported neck pain (NP) visual analogue scale scores (mm) for the high and low adherers pre- and post-season

The statistical analysis of the VAS scores for NP provides an indication of the overall effect of the intervention; however, what may also be of value is an examination of individual response to the intervention. Linton (317) suggested that a reduction of 10 mm on the VAS is the minimal value required to indicate clinical importance. In contrast, Forouzanfar et al. (318) proposed a relative pain reduction of 50% or more and an absolute pain reduction of at least 30 mm on the VAS was needed to accurately predict pain reduction after a treatment. Given that the mean reported baseline value for current, average or worst NP in our samples did not exceed 24.65 mm, a 30 mm decrease was not possible. Therefore, a 10 mm decrease was taken to indicate whether a reduction was clinically important. The HA produced a 10 mm drop in self-reported VAS scores in 20% of the individuals for current, average and worst NP. For the LA, a 10 mm reduction was achieved by 12.5% of the participants for current NP, 31.25% for average NP, and 37.5% for worst NP. In comparison to the 10 mm decrease, a relative pain reduction of 50% was also used to determine whether the treatment was successful. Based on this criterion, the HA achieved a 50% reduction in VAS scores in 40% of the subjects for both current and average NP and 30% of the subjects for worst NP.
This decrease was achieved by 31.25% of the LA cohort for current and average NP, and 25% for worst NP.

7.4.9 Neck stiffness visual analogue scores

7.4.9.1 Neck intervention group vs controls

The other purpose of this study was to observe any changes in self-reported NS in response to the implementation of a neck specific intervention relative to a control cohort that was not receiving the intervention. During the pre-season assessment, 23.08% of the participants in the NG reported having no current NS, and this value increased to 34.62% post-season. For the CON sample during the pre-season, 46.67% reported having no NS; this value decreased to 26.67% during the post-season assessment (Figure 7.10). Dependent t-tests for the NG indicated that NS remained unchanged for current, \( t_{(25)} = 0.10, p = 0.92 \), average, \( t_{(25)} = -0.27, p = 0.79 \), and worst, \( t_{(25)} = 0.15, p = 0.88 \), over the season. From the pre- to post-season current NS, \( t_{(14)} = 1.70, p = 0.141 \), and worst NS, \( t_{(14)} = 1.64, p = 0.12 \), for the CON remained unchanged, while average NS increased, \( t_{(14)} = 2.77, p = 0.02 \).
To determine whether there was a difference in self-reported NS response between the NG and the CON, a one-way ANOVA was conducted on the difference scores for current, average and worst NS. No statistical differences were observed for current NS, $F_{(1,39)}=1.70$, $p=0.20$, or worst NS, $F_{(1,39)}=2.06$, $p=0.16$, over the season. There was a statistically significant difference between the two groups for average NS, $F_{(1,39)}=6.17$, $p=0.02$, which is likely attributed to an increase in NS observed in the CON (Table 7.12).

Figure 7.10: Pre- and post-season visual analogue scale scores (mm) for the neck intervention (NG) and control group (CON) for current, average and worst neck stiffness over the past 3 weeks

* Indicates statistical significance at the 0.05 level
**Table 7.12**: Pre- and post-season visual analogue scale scores (mm) for the neck intervention (NG) and control group (CON) for current, average and worst neck stiffness over the past 3 weeks

<table>
<thead>
<tr>
<th>Visual analogue scale (mm)</th>
<th>Group</th>
<th>Pre-season</th>
<th></th>
<th>Post-season</th>
<th></th>
<th>95% Confidence interval</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>Δ</td>
<td>Lower bound</td>
</tr>
<tr>
<td>Current NS</td>
<td>NG</td>
<td>20.35</td>
<td>20.68</td>
<td>20.79</td>
<td>21.92</td>
<td>0.44</td>
<td>-9.67</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>12.97</td>
<td>16.63</td>
<td>24.13</td>
<td>22.43</td>
<td>11.17</td>
<td>-2.96</td>
</tr>
<tr>
<td>Avg NS</td>
<td>NG</td>
<td>17.78</td>
<td>19.16</td>
<td>18.62</td>
<td>18.15</td>
<td>0.84</td>
<td>-5.76</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>9.83</td>
<td>9.56</td>
<td>25.87</td>
<td>21.94</td>
<td>16.03*</td>
<td>3.63</td>
</tr>
<tr>
<td>Worst NS</td>
<td>NG</td>
<td>31.96</td>
<td>26.94</td>
<td>32.81</td>
<td>29.37</td>
<td>0.84</td>
<td>-13.33</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>35.73</td>
<td>23.53</td>
<td>52.60</td>
<td>31.45</td>
<td>16.87</td>
<td>-38.97</td>
</tr>
</tbody>
</table>

* Indicates statistical significance at the 0.05 level
7.4.9.2 High vs low adherers

The purpose of this analysis was to observe any changes in self-reported NS in response to the implementation of a neck specific intervention. During the pre-season assessment for the HA, 16.67% of the individuals reported having no current NS and this value decreased to 10.00% post-season. For the LA during the pre-season, 17.65% reported having no NS this value increased to 31.25% during the post-season assessment.

To determine whether there was a difference in self-reported NS response between the HA and LA, a one-way ANOVA was conducted on the difference scores for current, average and worst NS (Table 7.13). No statistical differences were observed for current, $F_{(1,24)}= 0.98, p= 0.33$, average, $F_{(1,24)}= 0.04, p= 0.85$, or worst, $F_{(1,24)}= 1.41, p= 0.25$, NS over the season. Dependent t-tests were conducted to examine the change in NS over the season and for the HA current NS, $t_{(9)}= 1.37, p= 0.20$, average NS, $t_{(9)}= 0.02, p= 0.99$, and worst NS, $t_{(9)}= 1.00, p= 0.34$, remained unchanged. Similar to the HA, the LA NS scores remained unchanged over the course of the intervention for all three VAS scales (current: $t_{(15)}= 0.46, p= 0.65$; average: $t_{(15)}= 0.33, p= 0.74$; worst: $t_{(15)}= 0.63, p= 0.54$) as seen in Figure 7.11.

Table 7.13: Current, average and worst self-reported neck stiffness (NS) visual analogue scale scores (mm) for the low (LA) and high adherers (HA) pre- and post-season

<table>
<thead>
<tr>
<th>Visual analogue scores (mm)</th>
<th>Group</th>
<th>Pre</th>
<th>Post</th>
<th>Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Current NS</td>
<td>LA</td>
<td>19.59</td>
<td>23.13</td>
<td>16.94</td>
</tr>
<tr>
<td></td>
<td>HA</td>
<td>18.71</td>
<td>16.74</td>
<td>26.95</td>
</tr>
<tr>
<td>Average NS</td>
<td>LA</td>
<td>16.74</td>
<td>19.61</td>
<td>18.88</td>
</tr>
<tr>
<td></td>
<td>HA</td>
<td>16.67</td>
<td>18.72</td>
<td>18.20</td>
</tr>
<tr>
<td>Worst NS</td>
<td>LA</td>
<td>31.94</td>
<td>31.41</td>
<td>28.72</td>
</tr>
<tr>
<td></td>
<td>HA</td>
<td>27.33</td>
<td>20.06</td>
<td>39.35</td>
</tr>
</tbody>
</table>

* Indicates statistical significance at the 0.05 level
The HA demonstrated a 10 mm drop in self-reported VAS scores in 20% of the individuals for current NS and a 30% for average and worst NS. For the LA, a 10 mm reduction was achieved by 18.75% of participants for current NS, 12.5% for average NS, and 25% for worst NS. In comparison, a relative pain reduction of 50% was achieved by 30% of the HA for current, average and worst NS. This decrease was achieved by 37.5% of the LA for current and worst NS, and 31.25% for average NS.

7.5 Discussion

The prescription of exercise therapy targeted at the neck as a method for the prevention of neck injuries in collision based sports is a commonly conducted practice based on little scientific evidence (54-57, 221). The primary purpose of this study was to investigate the efficacy of a neck specific exercise intervention over a competitive season in a professional rugby team. The success of the program was evaluated using pre- and post-season measures of neck strength, endurance, NP and NS and were compared to measures of a comparable group of professional rugby players who did not
receive the intervention. Over the season, the prescription of a neck specific intervention resulted in improvements in neck strength for Flx, LtFlx and RtFlx, while Ext remained unchanged. In contrast, those who did not receive the intervention tested weaker in all four directions post-season. For the %AUC and TTF endurance measures, the NG improved for RtFlx while the CON remained unchanged and decreased for LtFlx.

Over the season, participation in a neck exercise intervention did not yield any reductions in NP or NS, which have been observed in other studies (40, 42, 65, 71, 214). However, no increases in self-reported NP or NS were recorded for either the HA or LA post-season. While larger post-season worst NP and average NS scores were observed in CON. Thus, the prescription of a neck exercise program was successful in prevention increases in NP and NS symptom severity for players over a competitive season of rugby.

The primary aim of this study was to examine and compare the effectiveness of a neck exercise intervention implemented in a professional team relative to a control group. Research with professional teams offers a unique opportunity to examine the effectiveness of interventions in real-life situations where participants are exposed to the stresses of training and match play. Unfortunately, this type of research also involves practical constraints which the researcher has little control over such as the occurrence of injury, scheduling conflicts, training adherence issues, match play and a shifting in priorities as the season progresses. Although the timing of measurement in the control group was different than that of the intervention group, there is no reason to think that stresses over the one season would have been different from those in the following season at this level of professional rugby. Thus, it is felt that changes in the examined parameters across the competitive season between the intervention and control group are considered to reflect the protective effect of the intervention.

Since not all players adhered to the neck training protocol to the same extent, the secondary purpose of this study was to evaluate the effect of training adherence through the analysis of the results for the high and low responders. HA in the intervention group achieved improvements in peak force for Flx, LtFlx and RtFlx over the season while the LA remained unchanged. Improvements over the season were not limited to peak force, with the HA attaining enhanced endurance capacity for RtFlx %AUC and TTF
variables. These findings suggest that those with greater training adherence achieved the largest gains in neck strength and endurance. This outcome supports the use of a neck exercise intervention, incorporating strength, endurance, muscle coordination and impulsive loading components, to improve neck musculature strength and endurance in professional rugby players.

7.5.1 Participant anthropometric characteristics and normalization procedures

The observed variation in peak force measures with respect to body size metrics is well supported in the literature (4, 289). For the current sample, both neck circumference and body mass were correlated to peak force production. Similar results have been demonstrated in healthy undergraduate students (Chapter 3 Part II) and amateur rugby players (Chapter 5). Previous research examining weight-lifters and wrestlers has reported positive correlations between the cross-sectional area of the cervical semispinalis capitis muscle and body mass (293). In the current study, both body mass and neck circumference were correlated to peak force, however, when these variables were entered into an ANCOVA, only neck circumference was found to contribute to peak force production (4, 75). As forwards have larger necks than backs and the distribution of these two groups of players was unequal, normalizing peak force to neck circumference controlled for this variability within the study sample. This rationale is supported by research that has demonstrated positive correlations between Ext MVC and cervical extensor cross-sectional area (293-295).

For the current participants, an Ext and neck circumference correlation of \( r = 0.5 \) was obtained. In youth rugby players (15-18 yrs), neck circumference was not correlated to Ext peak force (\( r = 0.05 \)). The authors reported that Ext peak force was most strongly correlated to grip strength, \( r = 0.7 \) (75). The disparity between these findings and those of the current study can be explained by the physical maturation status of the participants. In the current study, the average age of the participants was 24.7 years, thus having reached physical maturity, in contrast to the study cohort examined by Hamilton et al. (75).

It is generally accepted that the capacity to develop force in a muscle is proportional to the cross-sectional area of the muscle (39, 303, 304). These findings extend to the cervical musculature (39, 294, 319, 320). A 12-week neck Ext strength intervention
resulted in a 13% increase in the combined cross-sectional area of nine cervical extensors, which translated into a 34% increase in peak Ext force (39). A number of authors have proposed that an increase in the cross-sectional area of neck musculature is likely to enhance dynamic stabilization of the cervical spine and prevent or reduce the severity of injury (39, 54, 92). In contrast to these findings, the current study observed no changes in neck circumference for the LA or the HA. Despite this observation, the HA achieved significant improvements in neck strength.

### 7.5.2 Peak force

Despite suggestions that non-specific resistance training undertaken in an upright posture is sufficient to stimulate strength adaptations or increases in the cross-sectional area of neck musculature, research has demonstrated that exercises targeted specifically to the neck are necessary to obtain these results (39, 168). In the current study, a neck specific exercise intervention with a professional rugby team resulted in improvements in Flx, LtFlx and RtFlx peak force, with no change in neck Ext strength. In a matched group that did not receive the intervention, strength values at the end of a competitive season were lower than pre-season measures in all four directions. Thus, a neck specific exercise program appears to mitigate the loss of Ext strength and improves Flx, LtFlx and RtFlx peak force production for elite rugby players.

Interpreting these findings is challenging as neck strength over a season at the professional level has not been examined in collision sports. Recent research has examined the effectiveness of a neck intervention in the prevention of neck injuries over a rugby season. While the intervention was successful in reducing the number of match neck injuries sustained, strength testing was only carried out prior to the season and at week five, with the authors reporting no change in neck strength as a result of the intervention (73). In contrast, Ylinen et al. (94) compared the effects of a strength versus an endurance exercise intervention on neck musculature peak force in middle aged women diagnosed with chronic nonspecific NP. Over the year-long intervention, the authors reported the greatest strength gains for the two intervention groups occurred at two months, relative to a control group. The conflicting evidence regarding the improvements in neck strength in the aforementioned studies following an intervention is likely a reflection of the samples used. Despite this fact, the results of the current study are consistent with previous work using a range of populations that have
documented improved neck strength following an intervention (39, 65, 71, 72, 93, 94, 168, 181, 195, 302).

In the current study with no neck exercise intervention in place neck strength decreased from pre- to post-season. This finding is not unique to this study. Research examining the effectiveness of a supervised 8-month neck intervention in fighter pilots documented decreases in neck Ext peak force in participants that were prescribed the exercises but received no supervision (72). This observed decrease could potentially be explained by poor adherence to the program in these unsupervised individuals. The majority of research using a control cohort to examine the efficacy of neck exercise intervention, have not observed changes in the controls peak forces measures post-intervention (39, 71, 93, 168, 181). In contrast, one study in which the effects of two separate neck exercise interventions relative to a control were examined over a year, a 7-10% increase in Ext, Flx, left and right rotation strength in the controls was reported (94). The decrease in neck strength observed in the CON in the current study highlights the loads that rugby participation places on the necks of players.

Although injury surveillance was not conducted in the present study, others have reported an increased frequency of neck injuries as the professional rugby season progresses (20, 30). For amateur players, increased neck strength has been documented over a season (Chapter 5), which coincides with a reduction in the frequency of neck injuries at this level (87). Based on this finding, one could speculate that the increased frequency of neck injuries in professional rugby players over the season (20, 30) may be attributed to the parallel decrease in neck strength observed in the current study. This speculation is supported by Naish et al. (73) who reported a reduction in neck injuries sustained during game play when an isometric neck exercise intervention was introduced in a Super 15 rugby team. However, this study did not evaluate neck strength at the end of the season. These findings highlight the need for further research combining injury surveillance in conjunction with evaluation of neuromuscular parameters over a competitive season.

In the current study, the neck exercise program was not incorporated into the gym training sessions during the regular season, rather it was made optional for those players who were interested. Thus, during the regular season, for those participating in the study, the mean training attendance dropped to 25.4%, compared to the 85.2%
recorded during the pre-season. As expected, players who completed the neck intervention program on a regular basis achieved the greatest improvements in peak force. Those with high adherence attained improvements in peak force for Flx (25.8%), LtFlx (15.9%) and RtFlx (22.3%), while the LA remained unchanged for the four examined directions (-8.9 to 1.3%). Comparison of the current study with other research is difficult as the majority of intervention studies are typically shorter in duration, use controlled designs (90, 91) or do not report training adherence (73). For example, Mansell et al. (91) examined the effect of an 8-week isotonic cervical resistance training program with football players and reported no change in Flx (8.1% decrease) or Ext (10.5% increase) peak force. A similar length study compared the effect of isoinertial cervical resistance training in American gridiron players and reported an increase of 7% for Ext and 10% for LtFlx (90). Relative to the current study, these findings are comparable to the percent change observed in the LA, but are approximately half the value observed for the HA. Given the length of the current intervention (31 wks), the improvements observed for the HA are not unexpected. However, the percent changes observed for the LA over the 31-week intervention likely reflects the low training stimulus due to a lack of participation during the regular season and is comparable to changes observed in the two, 8-week interventions of two-three sessions per week discussed previously (90, 91). When the results of the LA are compared to those of the CON, the LA did not experience a decrease in neck strength over the season. These findings suggest that the training adherence for the LA was sufficient to prevent loss of neck strength over the season.

Another confounding factor in the interpretation of these results is that players in the current study were actively competing in Super Rugby 15 league at the time of the intervention. The study by Mansell et al. (91) examined football players in their off-season, while Lisman et al. (90) failed to report the stage in the season the gridiron players were at. As minor neck injuries occur at a relatively high frequency for professional rugby players during game play (20, 30), it is possible that these may have altered adherence to the intervention or impaired peak force production at the time of the post-season assessment (94). Thus, a more relevant comparison may be examination of interventions where the exposed population were completing activities identified as contributing to the development of NP at the time of the intervention. One such study utilized helicopter aircrew that were on active flying duty to examine the impact of a
12-week neck intervention program focused on cervical muscle coordination and endurance. After the intervention, an improvement in Flx (13.8%) and RtFlx (15.9%) were achieved (71). Although, smaller than the improvements observed in the HA, these findings are likely a more valid comparison for the current study as the aircrew were still flying and thus exposed to the stressors linked to the onset of flight related NP (68, 78, 272, 321).

Recently the effectiveness of a neck exercise program as an injury prevention measure has been examined in a professional rugby team over a competitive season. The intervention consisted of progressive isometric exercises that simulated the directions and angles of force player’s necks would likely experience during match play. Neck strength was assessed at the start of the season and five weeks into the intervention and no changes were observed. The authors suggested that the examined cohort were all well-conditioned athletes and that improvements in neck strength over the season were therefore unlikely (73). In the current study, the absence of peak force improvements over the season for the LA mirrors these findings. However, based on the prescribed frequency of two sessions per week, the training attendance for the participants in the study by Naish et al. (73), would likely be more comparable to that achieved by the HA. The lack of improvement in the study by Naish et al. could also suggest that the training stimulus in their intervention was insufficient to generate a strength adaptation. Thus the incorporation of dynamic endurance, muscle coordination, and impulsive loading exercises for the neck in addition to isometric strength exercises as seen in the current study is necessary to obtain improvements in neck strength, as demonstrated by the HA. Due to disparity between these studies in the follow-up time periods, it is difficult to compare results. Yet despite the lack of improvements in peak force recorded by Naish et al. (73), a reduction in the number of neck injuries sustained during match play over the season was observed.

### 7.5.3 Endurance

As cervical musculature endurance has not been examined previously in collision based athletes, a comparison to other research is not possible. Evaluation of the normalized peak force values achieved by the NG in the current study to those achieved by amateur players at the start of the season, demonstrates that professional players are stronger. These results could potentially suggest there is a transition in the neck muscle fibre
types of professional players toward Type II glycolytic fibres, which generate greater peak force values (322). Based on this proposed muscle fibre transition, professional players may present with impaired endurance capabilities in the cervical musculature, resulting in decreased values for %AUC and TTF. The findings of the current study support this speculation, where the TTF values for the professional players were approximately half the value observed for the amateurs, with the exception of Flx (Chapter 5).

Differences were observed between the NG and the CON for LtFlx and RtFlx endurance during the pre- and post-season assessment. For LtFlx %AUC and TTF values, the CON was observed to decrease post-season, while improvements were seen for these values for RtFlx in the NG. When comparing the submaximal endurance values for the NG and CON pre-season, the mean values for LtFlx were higher than those observed for RtFlx. This same trend was observed in amateur rugby forwards and backs at the start and end of the season. For both the amateurs (Chapter 5) and the professional players in the current study, the majority were right handed. In research examining normative neck strength in the general population (20-84 yrs), RtFlx tested stronger than LtFlx (323). Given the large portion of the rugby players in the current cohort were right-handed, it would be expected that RtFlx would have presented with enhanced endurance capabilities, however, this was not the case. Research on helicopter aircrew has reported similar left-right side discrepancies (5, 68, 71, 164). These authors propose that some common occupational factor such as the ergonomic design of the helicopter or posture adopted during flight may potentially explain the impaired function of the neck musculature on the right side of the neck despite the predominant right-handedness of the population (5, 71, 117). For the current study, these findings suggest that given the preference to tackle with their right shoulder (85% of the current cohort), injuries sustained or the accumulation of microtrauma over the season/career of a player have impaired neuromuscular functioning on this side of the neck. For the NG, in the current study the application of the intervention successfully reduced the %AUC LtFlx:RtFlx ratio from 1.3:1.0 pre-season to 0.9:1.0 post-season. This improvement can be attributed to the increase in %AUC and TTF values for RtFlx that were observed post-season. These same improvements in the LtFlx:RtFlx ratio and RtFlx TTF results were observed in a helicopter aircrew after a 12-week neck exercise intervention focusing on muscle coordination and endurance (71). These findings
suggest: (a) transition in the muscle fibres over the course of the intervention from glycolytic to more oxidative metabolic properties, (b) hypertrophy of the Type 1 muscle fibres in this region, or (c) improved neuromuscular recruitment patterns (309, 322).

Analysis of the submaximal endurance results revealed a large amount of variability for %AUC and TTF over the season for both the LA and HA, which is consistent with observations in amateur rugby players (Chapter 5). This variability impairs the ability to isolate potentially statistically significant findings between the LA and HA. Despite the large amount of variability, differences were observed between the LA and HA for Flx, LtFlx, and RtFlx. For Flx, a group effect was observed, where the HA achieved larger %AUC and TTF than the LA when collapsed across time. This outcome is potentially explained by the larger percentage of forwards in the HA whose cervical flexors would be exposed to greater metabolic demands during the game (scrummaging, rucking and mauling), resulting in enhanced endurance capacity in these muscles. This pattern, however, was not observed for the other three directions. Of particular interest is the absence of this group effect for Ext given the large isometric demands placed on this musculature in forwards during static phases of play in rugby (scrummaging, rucking, mauling) (151). For LtFlx, a decrease of -3.14 %AUC and -2.03 s for the LA was observed over the season and was different from the improvement recorded for the HA, 30.53 %AUC and 36.74 s, respectively. These findings indicate that greater adherence to the neck intervention resulted in improved LtFlx endurance capacity. However, when examined independently, the improvements in %AUC and TTF for the HA were not large enough to reach statistical significance (%ACU: p = 0.07; TTF: p = 0.06), which is likely a reflection of the limited sample size.

A comparison of the left-right side difference pre-season for both the HA and LA for %AUC and TTF revealed that left lateral flexors had enhanced endurance capabilities when compared to the right lateral flexors (LtFlx:RtFlx ratio: LA: 1.0:0.77 and HA: 1.0:0.76). The application of the neck specific intervention displayed a positive trend towards reducing this left-right side difference, as post-season %AUC and TTF tested stronger on the right side in both HA and LA. Post-season %AUC for the HA achieved an approximate balance between left and right sides, with a 1.0:1.06 ratio, while the LA tested slightly stronger for RtFlx 1.0:1.14. In contrast, the Ext:Flx endurance ratio for
%AUC and TTF for both the LA and HA displayed the opposite trend to the LtFlx:RtFlx ratio. For the LA, the disparity between the %AUC values for the extensors and flexors grew from 0.82:1.00 pre-season to 0.63:1.00 post-season. The HA achieved similar results with a pre-season ratio of 0.87:1.00 to a post-season 0.67:1.00. These findings suggest that either a greater training response was achieved by the cervical flexors when compared to the extensors or that the competitive season imposed a larger stress on the cervical extensors impairing the training response in these muscles. Given that similar results were observed for both the LA and HA, it is likely that the latter is a more plausible explanation. This finding is further supported by the lack of change observed in the peak force variables for the extensors of both LA and HA.

7.5.4 Neck pain and neck stiffness

A number of intervention studies have documented reduced self-reported NP following the completion of a neck specific intervention (40, 65, 71, 284). In the current study, the application of a neck intervention consisting of strength, endurance, muscle coordination and impulse loading exercises did not reduce self-reported NP or NS in a cohort of professional players. However, the intervention did prevent increases in worst NP and average NS that were reported in the CON post-season. Comparisons with prior research are difficult as the occupational environment of the study populations varies greatly. Rugby players are continually exposed to impulsive loading events to the head and neck region at trainings throughout the week and during weekly matches. At the professional level during a match, an average of 221 tackle events occur (100). Although the forces experienced at the neck in rugby players has not been examined during the tackle, work with American gridiron players, utilizing helmets instrumented with linear accelerometers, has shown that the average head acceleration associated with impacts ranges from 21 to 32 +Gz (144-147). Although these would likely be higher than those achieved during an impact event in rugby, they provide some insight into the force vectors experienced during these collision events. Analysis of the force vectors experienced by the necks of front row forwards in the scrum has been documented and is reported to be up to two-thirds of a tonne (151). Given these findings, it is unlikely that professional players would achieve reductions in NP and/or NS over the course of a season. However, preventing an increase in the severity of the NP and/or NS may be a significant achievement for this population.
In the CON population, an increase in worst NP and average NS were observed when the post-season values were compared to pre-season scores. In contrast to these findings, increases in current, average and worst NP were observed when monitored over a competitive season for amateur forwards and backs, with the exception of average NP for backs. In addition, increases in current, average and worst NS were also observed for the backs while the forwards remained unchanged (Chapter 5). These findings would suggest that limited increases in NP and NS were observed for professional players when compared to their amateur counterparts. Given the increased frequency of neck injuries in professional players (20, 30, 36) and the higher force vectors experienced during collisions due to the increased speed and size of the players, this finding is unlikely (9, 15-17, 111). What may be a more feasible explanation is the under-reporting of NP and NS severity by the professional players. When the combined VAS scores for current NP pre-season were examined in amateurs (forwards and backs) and in professionals (NG and CON), they were approximately similar, 7.3 mm and 9.44 mm, respectively. However, post-season the amateurs’ current NP scores increased to 25.1 mm, while a smaller increase (20.2 mm) was observed for the professional players not exposed to an intervention. As the Super 15 season was substantially longer (31 wks) when compared to the amateur season (20 wks), players may have adjusted to a certain level of NP and/or NS and may under-report its severity. Similar issues have been observed in the assessment of NP severity in military populations (68, 71).

In the current study, no changes in self-reported current, average or worst NP or NS were observed for either the HA or LA after the neck specific intervention. These finding are in contrast to work by Nikander et al. (40) who compared the effects of a strength and an endurance neck exercise training program on perceived NP and disability in female office workers with chronic NP. They reported that the greatest dosage of the specific training had the largest effect on NP symptoms. These findings are consistent with other research examining chronic NP patients within the general population (40, 42, 67, 93, 94, 214), military helicopter pilots (65, 71, 324) and fighter pilots (195, 302, 325) where the prescription of a neck specific intervention resulted in significant decreases in self-reported NP symptoms.

This method of NP assessment has been used in previous research examining self-reported NP in the general population (284) and with helicopter aircrew (6, 71). The
lack of change in current NP scores observed in the current study were also reported for the females with work-related trapezius myalgia (284) and the helicopter aircrew with chronic NP (6, 71). A possible explanation for this consistent pattern across these studies is the high level of individual variability in current NP symptoms. However, for average and worst NP the participants in the studies by Ahlgren et al. (284) and Salmon et al. (71) achieved statistically significant reductions following neck exercise interventions. This trend was not observed in the current study. These conflicting results may be a function of the lack of consistent attendance during the regular season in the current study where that average attendance for both the HA and LA ranged from 10.6% to 40.2%. However, the study by Salmon et al. (71) reported similar adherence to that achieved by the HA and observed significant decrease in NP for both an endurance based neck exercise intervention and a muscle coordination exercise program. Thus, a more feasible explanation for the observed difference is that the repetitive trauma sustained by the neck during a competitive season of rugby would preclude the likelihood that an individual would not be experiencing some form of post-season NP or NS.

The construct of NS has not been previously examined in professional rugby. It was included in the current study to explore the perceived functional limitations in cervical ROM due to muscle and/or joint stiffness experienced by players. During the pre-season assessment 23% of the NG reported having no current NS which increased to 35% post-season. The opposite pattern was observed for the CON with 47% reporting no NS pre-season which decreased to 27% during the post-season assessment. These findings suggest that completing neck exercises during the season mitigates the symptoms of joint and/or muscle stiffness in the neck.

The percentage of individuals reporting no NP during the post-season assessment actually increased from 41% to 50% for the LA and from 50% to 60% for the HA. These findings would suggest that the intervention was successful for both the HA and LA in preventing increases in the occurrence and symptom severity of NP over the competitive season. Despite the improved neuromuscular function achieved by the HA, there was no difference in the self-reported NP or NS VAS scores between the two intervention groups. Anecdotally, the participants during the regular season with the highest training adherence were those who self-reported the most frequent occurrence
of “stingers” (neck traction injuries) or minor neck injuries. This observed self-selection bias may have impaired the ability to isolate any difference in the post-season NP or NS scores between the HA and LA.

Data analysis regarding the sensitivity and specificity of VAS scores in regards to the complex regional pain syndrome indicates that a cut-off point for the likelihood that a participant will report their treatment as successful is a 50% relative pain reduction (318). Based on this criterion, the HA achieved a 50% reduction in VAS scores in 40% of the participants for both current and average NP and 30% for worst NP. This same decrease was achieved by 31% of the LA cohort for current and average NP, and 25% for worst NP. In comparison, a relative pain reduction of 50% was achieved by 30% of the HA for current, average and worst NS. This decrease was achieved by 38% of the LA for current and worst NS, and 31% for average NS. Although NS was not examined in the study by Salmon et al. (71), similar reductions in NP were observed for the helicopter aircrew assigned to a neck muscle endurance or muscle coordination program for the neck.

### 7.6 Conclusion

In conclusion, this study was the first to examine the effectiveness of a neck intervention in a collision based sport over a competitive season using a pre- and post-season neck strength and endurance assessments. The application of a neck exercise intervention consisting of: (a) muscle coordination focusing on the deep cervical stabilizers, (b) neck muscle endurance through a dynamic range of motion, (c) isometric strength in a neutral position and (d) impulsive loading using low level resistance in a neutral neck position resulted in improvements in neck strength for Flx, LtFlx, and RtFlx. In contrast, with no intervention in place, decreases in neck strength were observed for a professional team when their post-season strength values were compared with their pre-season scores. For the endurance measures, improvements were observed for RtFlx for the NG while the CON remained unchanged and even decreased for LtFlx. Despite these neuromuscular improvements observed for the NG, no changes in self-reported NP or NS were recorded, which is supported by research in other populations following neck exercise interventions in which no effect on NP or NS was observed (40, 42, 65, 71). These findings suggest that participation in rugby imposes large physical stresses on the cervical musculature and decreases in NP and NS
over a season are unlikely. The results recorded for the CON support this conclusion, as decreased neuromuscular function occurred in parallel with increased worst NP and NS scores. However, caution must be employed when interpreting these findings due to the limitation of the study design with respect to the timing of assessments for the control group. As neck pain is one of the primary symptoms of minor neck injuries, it is possible that the intervention may have potentially limited the occurrence of these injuries. This hypothesis is speculative and warrants further examination in conjunction with injury surveillance.
Chapter 8

Summary, Strengths and Limitations, Future Research Directions and Conclusions
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Chapter 8 – Summary and Conclusion

8.1 Introduction

In the research presented in this thesis a multi-study approach was employed to examine neck pain (NP), neck stiffness (NS) and neuromuscular function of the neck in rugby players. The primary aim of this research was the design and development of a neck exercise intervention, and an examination of its effectiveness over a competitive season in professional rugby players. A review of literature (Chapter 2) examined the current evidence from injury surveillance studies on neck injuries and the possible mechanisms or factors that could modulate the occurrence of these events. A retrospective study (Chapter 3) of retired professional players representing several rugby playing nations was conducted to explore whether injuries sustained during a career affect the long-term health and current lifestyles of these individuals. As highlighted in the literature review, improving neck muscle strength and endurance may provide a feasible strategy to reduce or mitigate the occurrence of minor neck injuries. Chapter 4 described the design, development and evaluation of testing apparatus capable of reliably assessing neck strength and endurance in a simulated contact posture. In Chapter 5 this device and VAS were used to explore changes in neuromuscular function of the neck, and self-reported NP and NS over a season of rugby participation. Based on these findings and evidence reviewed in the literature, a neck strengthening intervention for rugby players was developed (Chapter 6). The effectiveness of this intervention was then examined using assessments of neuromuscular function and self-reported NP and NS. A professional rugby team was followed over a season and compared to a control team that did not receive the intervention (Chapter 7). The present chapter provides a concise overview of the work undertaken and its contributions to the field of sports medicine and exercise prescription, and offers suggestions for further investigations in this area. The aims of this chapter are to:

1. Summarise the key findings of the thesis.
2. Draw conclusions based upon these key findings.
3. Note the strengths and acknowledge the limitations of the thesis.
4. Generate recommendations for future research.
8.2 Thesis Summary

A systematic and sequenced approach was employed in this thesis to examine the effectiveness of a neck exercise intervention in professional rugby players. The retrospective survey analysis revealed that NP and NS are frequently reported current health complaints for retired professional rugby players. The majority of players surveyed sustained a neck injury (79%) during their careers. Of those who sustained an neck injury during their careers, 91% reported currently experiencing symptoms of either NP and/or NS. This is supported by research on the long-term health outcomes for individuals following a whiplash injury sustained during a motor vehicle accident (249, 312). These findings indicate that most professional players will sustain a neck injury, and that this injury or the accumulation of microtrauma in the neck region over their careers, will have long-term health and disability consequences.

Given the likely impact a history of neck injury(ies) will have on a player’s quality of life once they retire, further research into the prevention of these injuries for current players is warranted. Van Mechelen’s ‘Sequence of Prevention’ model indicates that the first step in the development of prevention measures is injury surveillance (21). The review of literature indicates that minor neck injuries occur relatively frequently in rugby (30, 36), forwards are at greater risk (20, 27, 30, 36), and neck injuries occur more often at the start of the amateur season (87), yet more injuries are sustained later in the professional season (20, 24, 30). A review of factors and mechanisms that influence the occurrence of neck injuries revealed that neck muscle strength and endurance play a role in mitigating or minimizing the occurrence of these injuries.

These findings led to the design and development of a testing apparatus that could be used to assess neck strength isometrically in a neutral position (Chapter 4: Part I and II). As the target population for this apparatus was rugby players, practical relevance of the measures was an important consideration. This concern led to the design of a device that assessed individuals in a simulated contact body posture, which differed from previous research in which neck strength and endurance were primarily examined in a seated position (58, 59, 95). In Chapter 4, research with university students determined the inter-trial reliability of the device was good to excellent for both the strength and endurance measures.
The next step was to monitor neck strength and endurance in rugby players over a season (Chapter 5). Statistically significant improvements in strength over a season for all four directions for forwards and for Ext, Flx and LtFlx for backs were observed, while non-playing controls remained unchanged. No changes in endurance were observed for the three groups over the season, likely due to the high individual variability in these measures. These findings suggest that participation in a season of amateur rugby imposes a physical stress on the neck musculature which leads to strength adaptation over the season. For both forwards and backs, increases in NP were observed over the season, while only the backs reported increases in NS over the season. These results suggest that despite improvements in neck strength over the season, both forwards and backs perceived neck function was impaired, while the controls reported no change.

Based on evidence collected in the review of the literature (Chapter 2) and the findings from Chapter 5, a neck specific exercise intervention was designed. This intervention consisted of four key components: (a) neck strength, (b) neck muscular endurance, (c) neck muscle coordination and (d) impulse loading of the neck. Each component was designed to address an injury pattern or mechanism of injury observed in rugby, such as neck strength to maintain stability of this region during scrummaging or improved neuromuscular coordination to enhance dynamic stabilization during tackling. The effectiveness of this intervention was then examined in a professional rugby team over the course of a competitive season, relative to a control group. Pre- and post-season neck strength, endurance, NP and NS were examined. The intervention resulted in improved neck strength for Flx, LtFlx and RtFlx, while the control group displayed decreases in post-season neck strength for all four measured directions. For the neck muscle endurance measures, improvements were observed for RtFlx for the intervention group while the control remained unchanged and even decreased for LtFlx. Despite the observed improvements in neck strength and endurance over the season, the NP and NS scores remained unchanged for the intervention group. In contrast, the control group reported increases in post-season NP and NS. This suggests that the forces experienced during contact, neck muscle fatigue, length of the season and conditioning status of the athlete culminate to highlight the large physical and perceived stresses imposed on the neck during the professional rugby competition. This is illustrated by the impaired neck strength and endurance function and the increased
post-season NP and NS scores observed over the season for the controls. In contrast, the prescription of and adherence to a neck exercise programme produced improvements in neck strength and endurance over a season. While the intervention failed to change self-reported NP or NS, the neck exercise intervention did prevent increases in symptom severity when compared to the controls. Thus, the application of neck exercise intervention in a professional rugby team will improve neuromuscular function (neck strength and endurance) and may play a role in preventing an increase in NP and NS over the season.

### 8.3 Strengths and Limitations

A strength of this thesis was the holistic approach used to examine neck strength, endurance, NP and NS in rugby players. Using van Mechelen’s ‘Sequence of Prevention’ framework ensured that a logical pathway for the development of the research paradigm was followed. To examine these factors, this thesis research employed a number of methodological approaches including: a survey, development and design of a strength testing apparatus, analysis of the validity and reliability of the measures obtained using the apparatus, monitoring of strength and endurance measures over a season, design of a neck exercise intervention and examination of the effectiveness of this intervention over a rugby season. The strength and endurance measures used to assess the reliability of the device and to monitor the effect of a season and intervention were consistent and used repeatedly throughout this thesis. These factors culminate to provide a unified theme throughout the studies examined in this thesis.

Another strength of this thesis was the design of a novel testing apparatus that assessed neck strength in a neutral position in a simulated contact body posture. Use of this body posture builds on previous work that has been conducted in the seated position (74-76, 88) and provides measures of neck strength and endurance in a posture that is more functionally relevant for collision sports such as rugby. Key considerations in the design of this device were the following: (a) portability, as the majority of strength assessments were done pitch side or in the gym; (b) assessment of neck function in a neutral posture, as pathological changes have been observed in the necks of rugby players and this position has been recommended to reduce risk of injury (47, 83, 98);
(c) time commitments, as keeping testing time to a minimum to maximize recruitment numbers was desired.

The primary limitation of this thesis was the lack of a temporally matched control group for the intervention study. Due to unforeseen circumstances beyond the control of the candidate, an ‘ideal’ control group that had been recruited for the designed protocol was subsequently unable to commit to the study. The timeframe of this research did not permit the use of a temporally matched control group, which would have been highly desirable. Despite this limitation, the recruited control group was a professional team exposed to the same competition schedule as the intervention participants and thus provided an adequate comparison. Since only control participants playing in both the 2012 and 2013 Super 15 seasons were eligible to participate, the sample size was limited. Both the sample size and the timing of the control group measurements represent limitations to this study. These limitations reflect the difficulty of conducting research in a professional sports team environment within the constraints of a PhD research project.

Given the time constraints and the limited access to power outlets, EMG measures were not included in this study. The lack of neurophysiological measures of neck function is a limitation of this thesis. Use of these measures would have provided insight into the muscle recruitment patterns and the activation of the deep stabilizers. As components of this exercise program focused on addressing aberrant muscle recruitment patterns observed in other populations (61, 67-69, 78, 125, 172, 180, 183) (249), use of EMG would have also provided insight into these issues in rugby players. While acknowledging the global strengths and limitation, there are a number of strengths and limitations associated with the individual studies contributing to this dissertation. A detailed list of the strengths and limitations for each study is illustrated in Table 8.1.
## Table 8.1: The strengths and limitations of the respective studies examined in this thesis

<table>
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<tr>
<th>Study</th>
<th>Strengths</th>
<th>Limitations</th>
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| Chapter 3 | • First study to explore the relationship between neck injuries sustained during a career and the presence of NP and NS.  
• Multi-national study ensuring a wide range of players exposed to various training conditions.  
• Extensive development of content and piloting of survey  
• User friendly question format  
• Use of adaptive questions | • Low response rate and inability to determine exact response rate  
• Potential selection bias  
• Single mode survey |
| Chapter 4 | • Development and design of the device was based on feedback from international level physiotherapist and scrum coach involved in rugby, in addition to local physiotherapists and strength and conditioning coaches who had numerous years of rugby involvement  
• First device to assess individuals in a simulated contact position  
• Reliability for strength and endurance measurements ranged from good to excellent  
• Device was rigorously tested over the course of two studies  
• Neck tested isometrically to limit the potential for injury | • Reliability test was conducted with university students  
• The neck posture adopted in the testing apparatus does not mirror the position recommended when making a tackle  
• Limited sample size of pilot studies |
| Chapter 5 | • First ecologically valid study to examine neck strength, endurance, NP and NS over a rugby season  
• Recruited forwards and backs were drawn from a sample of multiple teams  
• Changes over the season in these players were compared to healthy non-rugby controls  
• First study to examine neck muscular endurance in collision athletes | • Due to drop outs over the season and difficulties recruiting participants different sample sizes were used for the groups  
• Players were tested over a 4-week period at the start and end of the season. Thus, there may have been varying levels of rugby exposure at the time of testing. |
| Chapter 6 | Design of a neck exercise protocol based on evidence collected and examined from Phase 1 and 2 in the ‘Sequence of Prevention’ model  
- Inclusion of exercise components that have been successfully used to reduce symptoms of NP in other populations  
- Inclusion of exercises that had been used successfully in a case study examining rehabilitation of a front row forward  
- Considered the recommendations from positions papers for athletes in collision sports | Little scientific evidence for some of the components in the exercise program, specifically the use of low load impulsive exercises  
- With the exception of isometric exercises the intervention components have not been examined previously in rugby |
| --- | --- |
| Chapter 7 | First study to document the effectiveness of neck exercise protocol using pre- and post-season assessment of neck strength and endurance  
- Inclusion of a professional rugby team also competing in the Super 15 league as the control group  
- Player attendance was documented to determine effect of training adherence  
- First study to examine the effectiveness of a neck exercise intervention using self-reported NP and NS  
- All neck exercise sessions were supervised  
- Real world pragmatic study with actively competing professional rugby teams | Lack of a temporally matched control group  
- Training adherence in the intervention group dropped during the regular season  
- Sample size of the controls differed from the intervention group  
- No injury surveillance data were collected |
8.4 Future Research Directions

While the knowledge gained from research presented in this thesis is useful in its own right, and has the potential to contribute to the literature of sports science, the development of the survey, testing apparatus and neck exercise intervention also identified several avenues of research that deserve further exploration. The potential areas of research are outlined below.

**Retrospective analysis of the health status of retired professional players relative to age matched controls.** While the survey conducted in Chapter 3 provides the first initial insight into the long-term health consequences of neck injuries sustained during a rugby career. Comparison of the data recorded here to age matched controls would provide the opportunity to differentiate the pathological changes related to injury from those attributed to the normal aging process.

**Neuromuscular function assessment in conjunction with and injury surveillance.** Use of the testing apparatus to assess a larger population, in conjunction with neck injury surveillance would clarify the link between neck strength and the occurrence of injury. Due to the large endurance measure variability and time requirements, future research may consider only testing neck strength and not neck endurance. Neck strength can be assessed in a 5 min timeframe per player and still provide valuable insight into neck function. This strategy would facilitate recruitment of a larger population that would enhance the statistical power of the study. In addition, due to the difficulty in collecting accurate injury surveillance data, future research could be focussed on specific competitions where medical personnel are a requirement and injury reporting is a standard procedure.

This same rationale would apply to the examination of the efficacy of the exercise intervention. The use of a larger population in conjunction with injury surveillance data would clarify the link between neuromuscular function in the neck and the occurrence of injury. Additionally, use of a time matched equivalent control group would provide a stronger research design to compare changes in the intervention group. Assessment over multiple seasons would also provide insight into the efficacy of the neck exercise intervention. The use of a randomization procedure is not likely to be feasible due to the logistical considerations of prescribing an intervention to only certain players on a
professional team. Thus more pragmatic approaches to research in the professional sports team environment are necessary.

**Modification of the injury surveillance process.** The potential for the neck musculature to prevent catastrophic or major neck injuries is likely limited as the forces experienced during collisions exceed the tensile strength of the musculature and structural capacity of the osteoligamentous system (54). Therefore it is likely that incorporation of neck exercises into a training program could potentially reduce or mitigate the severity of minor neck injuries. This raises the question as to whether the current consensus statement on injury definition (248) relating to the neck for rugby sufficiently captures the occurrence of minor neck injuries. This omission is highlighted by the increased NP scores reported by amateur forwards and backs over the season observed in Chapter 5. Previous work with players from the same playing grade reported a decreased occurrence in neck injuries during the latter half of the season (87). These results indicate the need for further measures, such as self-reported NP and NS to be used as an adjunct to traditional injury surveillance data, in order to capture the frequency of minor neck injuries which may not result in time lost from play or go unreported. This step may be necessary until further evidence is collected to understand the mechanisms of the documented pathological changes to both the osteoligamentous (47, 83) and neuromuscular systems (44, 48-51) observed in the cervical region.

**Examination of neurophysiological neck muscle function.** The use of EMG to examine neurophysiological function of the neck muscles of rugby players following a season or the application of a neck exercise intervention would provide further insight into the effect of these events. In addition, these measures would provide insight into whether the aberrant neuromuscular recruitment patterns observed in other populations with NP are present in rugby players with NP (61, 67-69, 78, 125, 172, 180, 183) (249).

**Design of an impulse loading device to assess neck muscle function.** As the majority of neck injuries are sustained during the tackle (11, 20, 30, 36), a testing apparatus and experimental procedure that assesses the muscle onset times of the primary stabilizers (upper trapezius and SCM) during an impulse loading event may provide a feasible strategy to examine the role of improved neck strength in the dynamic stabilization of the head-neck segment.
Potential application for concussion prevention. A number of studies have suggested that increased neck strength in the upper trapezius and sternocleidomastoid may potentially minimize linear head acceleration during impact, which has been linked to the severity of a concussion (89-91, 147, 311). Although the efficacy of a neck exercise intervention to prevent concussions or lessen symptoms severity has not been examined, it has been suggested that enhanced dynamic stabilization of the head-neck segment could reduce linear acceleration force experienced during contact (90-92). In addition, research has highlighted that the presence of NP prior to a season increases the risk of sustaining a concussion in ice hockey (301). This body of research implies a growing interest in the use of neck exercise interventions in collision sports as potential preventative measures.

Development of future exercise intervention programs for professional sports. As an independent researcher (the candidate) coming into a team environment, difficulties were encountered with training adherence and the shifting of team and athlete priorities. Future research may best be conducted by the strength and conditioning coach or associated medical personnel as an integral part of the training and/or conditioning program over the season. As there is now an awareness of the long-term effects neck injuries may have on the health of players, neck exercises should be a regular part of training programs.

8.5 Conclusion

Collectively, this corpus of work examined a number of interlinked studies relating to the exploration of neck strength, endurance, NP and NS in rugby players. The long-term consequences of neck injuries sustained during a career playing rugby were examined in retired professional players. The review of literature examined injury surveillance data regarding the occurrence of neck injuries, and the factors and mechanisms that contribute to these injuries. A novel testing apparatus and experimental protocol were designed and applied to test neck function, which allowed documentation of the neuromuscular impacts of participating in a competitive rugby season and neck specific intervention. In conjunction with these measures, NP and NS have also been examined to explore the perceived impact these events have on players. Finally, based upon evidence gathered over the course of this research, a neck specific exercise intervention was designed and implemented in a team of professional rugby
players. The findings of which provide preliminary evidence to support the adoption of a neck exercise program for professional rugby players to prevent increases in NP and NS symptom severity. This thesis has identified and addressed gaps in the literature regarding these variables and, therefore, has the potential to make significant contributions to the science of rugby.
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