Measuring the Physical Activity of Children aged 3 to 7 years

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ABSTRACT

Introduction
Obesity has become epidemic throughout the world and is affecting both adults and children. New Zealand children have a high prevalence of being overweight, with estimates varying between 20% and 30%. Sedentary behaviour (SB) is an important mediator of successful prevention of developing overweight in children. However a reliable objective method for measuring SB is still lacking. Effective prevention of excessive weight gain could flow from having an objective device with a clear definition of SB. Accelerometers are motion sensing devices which have been used to study physical activity (PA) with promising validity in children. As one of the steps in establishing the utility of accelerometers in measuring SB, we aimed to assess the reliability and validity of the Actical accelerometer for its use in 3-7 year old children and to propose an appropriate cut-off that defines SB.

Methods
Children (N=50) aged 3-7 year old were recruited in Dunedin, New Zealand, to participate in the study. The study was carried out at the participants’ preschool centre or school. The children were asked to wear the Actical accelerometer around their waist and to perform numerous selected activities of varying levels of intensity. At the same time, participants were video recorded for observational analysis to provide the criterion measure of PA. Activities performed during free play sessions at participants’ preschool centre or school were also measured. Reliability of the Actical accelerometers was assessed daily throughout the data collection phase using a custom-made motion generator. Validity of the accelerometer was assessed by comparing with activity levels measured by direct observation using the Children’s Activity Rating Score (CARS). The appropriate cut-off to define SB was determined by plotting the receiver operating characteristic curve, and the cut-off derived was then cross-validated by comparing with levels of SB measured by using the CARS.
Results

Height, weight and BMI distributions of the children assessed (N=49) were comparable with published data on New Zealand children. Reliability tests during the data collection phase revealed high intra-instrument and inter-instrument reliabilities (r_p-intra & r_p-inter = 1.0). Repeated measurements by the same accelerometer gave small differences (<10% at low speed, <5% at and high speeds), whereas differences between accelerometers were greater (34-50% at low speed, <15% at moderate speed and <10% at high speed). Overall, 383 observations on 49 children were made for an average duration of 8.8 minutes. Total observation time across all children was approximately 3,370 minutes. The accelerometer counts for each type of activity were found to be significantly different (p<0.05) and were categorised into four groups: inactivity (Sleep), sedentary level movement (Draw, Play Doh, Puzzle, Read, TV), light level activities (Toy Car), activities of higher intensities (Nintendo Wii and Free Play). Using the receiver operating characteristic curve (area under the curve: 0.843), a cut-off of 40 counts/15s was identified (sensitivity: 88.44% and specificity: 64.63%). For the children assessed by the CARS (N=9), correlation between Actical counts and CARS score was moderate (r_p=0.56). The mean difference of percentage of time in sedentary activity judged by accelerometry compared to direct observation using CARS was 8.4%. There were no significant differences in the percentages of sedentary activity between accelerometer data versus CARS (p=0.055).

Conclusions

Overall, the study has proposed a cut-off for SB of 40 counts/15s. Despite having obtained moderate correlation with the criterion measure, it appears that this cut-off tends to slightly under predict levels of SB and accurate prediction of SB is limited by sub-optimal inter-instrument agreement. Performance of the Actical could be improved if accurate calibration were possible outside the manufacturer. Utility of the cut-off could be further assessed by conducting a cross-validation of the cut-off with a larger sized sample.

Outcome

The results of this study could be used in ongoing studies that use the Actical accelerometers to measure activity in children aged 3 to 7 years.
PREFACE AND ACKNOWLEDGEMENT

I would like to express my gratitude to all those who have supported me to complete this study. I want to thank the Dunedin School of Medicine and Otago School of Medical Sciences for giving me financial assistance to commence this study in the first instance. I would then like to thank the Paediatric Section, Department of Women’s and Children’s Health, especially the Head of Department, Professor Barry Taylor, for the guidance and supervision of the study throughout its course. Equally importantly, I want to thank Dr Rachael Taylor and Associate Professor Sheila Williams for your ongoing encouragement and the many advices on designing the study protocol, conducting data collection and drawing clarity from the data. Thank you all for introducing me to the challenging and exciting world of research.

My gratitude also goes to all the families who participated in the study. The visits to the Dunedin Hospital Early Childhood Centre were truly enjoyable and I thank Sue, Margaret and all the staff members there for having me around as ‘one of the team’. I have furthermore to thank Leanne Hill and the staff members at George Street Normal School, Nigel Wilson and the staff members at Kaikorai Primary School, for your wonderful help and hospitality. It has indeed been a memorable experience meeting you all and this study could not have happened without the help from you.

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To my family and friends, you have been behind me right from the very beginning, unconditionally caring for me and being patience with me. There have been stressful times and long hours of work to endure, but you have given me the vision, wisdom, health and courage to carry on. To my partner, Lily, I could not have been through everything without you. Thank you!
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<tr>
<td>AEE</td>
<td>Activity Energy Expenditure</td>
</tr>
<tr>
<td>BEACHES</td>
<td>Behaviours of Eating and Activity for Child Health: Evaluation System</td>
</tr>
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<td>BF</td>
<td>Body Fat</td>
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<tr>
<td>BMI</td>
<td>Body Mass Index</td>
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<tr>
<td>CARS</td>
<td>Children’s Activity Rating Score</td>
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<tr>
<td>CPM</td>
<td>Counts Per Minute</td>
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<td>DLW</td>
<td>Doubly-Labeled Water</td>
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<td>DO</td>
<td>Direct Observation</td>
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<td>EE</td>
<td>Energy Expenditure</td>
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<td>HDL</td>
<td>High-Density Lipoprotein</td>
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<td>HR</td>
<td>Heart Rate</td>
</tr>
<tr>
<td>ICC</td>
<td>Intraclass Correlation Coefficient</td>
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<td>IOTF</td>
<td>International Obesity Task Force</td>
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<tr>
<td>LDL</td>
<td>Low-Density Lipoprotein</td>
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<td>LPA</td>
<td>Light Physical Activity</td>
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<td>MET</td>
<td>Metabolic Equivalence</td>
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<td>MPA</td>
<td>Moderate Physical Activity</td>
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<td>MVPA</td>
<td>Moderate-Vigorous Physical Activity</td>
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<td>NASPE</td>
<td>National Association for Sport and Physical Education</td>
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<td>OSRAC-P</td>
<td>Observational System for Recording Physical Activity in Children-Preschool Version</td>
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<td>PA</td>
<td>Physical Activity</td>
</tr>
<tr>
<td>RCT</td>
<td>Randomised Controlled Trials</td>
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<tr>
<td>REE</td>
<td>Resting Energy Expenditure</td>
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<tr>
<td>RMR</td>
<td>Resting Metabolic Rate</td>
</tr>
<tr>
<td>ROC</td>
<td>Receiver Operating Characteristic (curve)</td>
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<tr>
<td>r_p</td>
<td>Pearson’s product-moment correlation coefficient</td>
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<td>SB</td>
<td>Sedentary Behaviour</td>
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<td>TEE</td>
<td>Total Energy Expenditure</td>
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<td>TG</td>
<td>Triglycerides</td>
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<td>VO2</td>
<td>O₂ consumption</td>
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<td>VPA</td>
<td>Vigorous Physical Activity</td>
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<td>WHO</td>
<td>World Health Organisation</td>
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CHAPTER 1: INTRODUCTION

1.1 Problem Statement

An increasing prevalence of overweight/obesity has been observed worldwide in both developed and developing nations, in both adult and child populations\cite{1-3}. It is a serious issue that has received ongoing attention in the scientific community and many studies have been carried out in search of its aetiology. Among the few strong predictors identified of excessive weight development, physical activity (PA) has been highlighted as a target for intervention in view of the high obesogenic effect from lack of PA, the many health benefits that derive from participating in PA and its potential amenability to change at both the individual and community levels\cite{4-8}. There have been studies suggesting that the habitual levels of PA are low and of sedentary behaviour (SB) are high in adults, children and even, to the surprise of many, preschool children\cite{9-13}. However, measuring activity levels has proven to be difficult and the search for a valid, reliable measuring tool that is accurate and feasible for studying activity levels at both the individual and at the population level has been a continuous focus of research over the past few decades.

Accelerometry is a technology that is considered by many to be state of the art in the development of PA measurement tools. An accelerometer is a small, unobtrusive, waterproof device which measures movement in three dimensions. It is objective, relatively cheap, easy to use and is capable of quantifying differing levels of activity. Among the different models of accelerometer available on the market, the Actical is the newest model which utilises omnidirectional technology. It has already shown promising potential as an accelerometer with highly consistent performance in validation studies\cite{14-15}. At the moment there has only been one published study in defining the cut-off of moderate-vigorous physical activity (MVPA) for preschool children. Pfeiffer et al\cite{16} utilised indirect calorimetry as the criterion measure of PA during which a strong correlation between PA-determined by accelerometry and oxygen consumption (VO2) was observed, and a cut-off for MVPA was derived. What remains undefined is a definition and cut-off for SB. It has been suggested that SB should be considered as an independent physiological construct\cite{17} and studies have demonstrated that targeting a reduction in SB may be more effective in preventing excessive weight gain in children than targeting increases in PA\cite{18-19}. 
1.2 Study Aims

From the literature discussed in the problem statement above and the background in the following chapters, the study aimed to achieve the following:

1) To define the upper limit in terms of counts per 15 seconds (Actical accelerometry) of sedentary behaviour in children 3-7 years of age.

2) To assess the reliability and validity of the Actical accelerometer in measuring physical activity in young children.

3) To use this knowledge to form the basis for future researchers to measure the levels of sedentary activity of the two-hundred-forty 3-7 year old children in a recent longitudinal study conducted in Dunedin, New Zealand\textsuperscript{[20]} and to describe correlating characteristics with high levels of sedentary activity.
1.3 Research Strategy

The rest of this thesis is divided into four chapters:

Chapter 2 introduces the concept of the global epidemic of overweight/obesity with a detailed review of the literature on the prevalence of overweight/obesity across the world. Background of the problem at stake is illustrated with a discussion on the impact of overweight/obesity to our children and our health system. This is followed by a description of the role of PA and how it has become one of the main targets for countering overweight. This section also outlines several additional health benefits associated with PA, while noting some risks involved in pursuing it. The discussion continues with an update on the current recommendations of PA type, frequency and duration from the different organisations, for children including preschoolers. Following this, the measurement of PA in preschoolers and utility of the various methods used and their advantages and disadvantages, are reviewed. This leads to identifying areas for future work on refining measurement of PA, and introduces the focus of the current thesis – measuring PA using the Actical accelerometer. Finally, the chapter concludes with a discussion on the role of SB in generating excessive weight, and how it fits in the picture of overweight/obesity treatment and prevention.

Chapter 3 describes the study design and methodology used to recruit participants and investigate the validity and reliability of the Actical accelerometer. How the device was compared against direct observation to assess its utility in measuring SB in children aged 3-7 years, is then described. The chapter finishes with a discussion on statistical techniques used to analyse data collected.

Chapter 4 presents the study sample demographics, followed by the results of reliability and validity testing and the cut-off derived to measure SB.

Chapter 5 discusses the study results with comparison to previously published results, followed by a discussion on identified strengths and limitations of the current study. Finally, areas for further research are proposed.
CHAPTER 2.1: A GLOBAL EPIDEMIC – OVERWEIGHT/OBESITY

2.1.1 Introduction

The high prevalence of overweight and obesity is now becoming ever more alarming in both developed and developing countries. In 2003, the World Health Organisation (WHO) estimated that more than one billion people are overweight and this was described as having reached ‘epidemic proportions’[3]. The International Obesity Task Force (IOTF) during their most recent analysis of the Global Burden of Disease estimated the different prevalence of overweight and obesity in middle aged men and women (45-59 years of age) for 191 countries around the world. The estimates by the IOTF defined sub-regional groupings are provided in Figure 1[1]. From Figure 1 it can be clearly seen that the prevalence of overweight/obesity is alarmingly high, largely in developed countries in Europe and America, where more than 50% of the populations were estimated to be overweight (inclusive of obesity). In developing countries, for example the African region, the prevalence of obesity varied widely. Places such as Ghana and Mali (which have maintained a traditional lifestyle) have maintained a low prevalence of obesity (about 0.85%)[21], while populations such as Cape Peninsula (which has improving socio-economic status) had high obesity prevalence especially in women (approximately 44% of women and 8% of men were estimated to be obese in 1990)[22].

The rapidly increasing prevalence of overweight and obesity has been reported by many studies. For example, the latest WHO Expert Technical Consultation on Obesity[3] reported the trends in overweight/obesity from around six WHO regions – Africa, Americas, Eastern Mediterranean, European, South-Eastern Asian and Western Pacific. Data from developed countries such as the European region (England, Finland, Germany, Netherlands and Sweden) indicated that the prevalence of obesity has increased by about 10-40% over the years from 1980-1995[23-27]. Data of trends in obesity prevalence were not available for some regions of developing countries, however based on the data available there was a marked increase in obesity prevalence over a five-year period similar to that seen in the developed countries. For example, in Mauritius the proportion of obesity increased from 3.4% to 5.3% in men and from 10.4% to 15.2 % in women over the years from 1987-1992[28-29].
Figure 1. Preliminary estimates of the prevalence of overweight and obesity in 45 to 59 year olds in different parts of the world by sub-regional groupings, described by the IOTF.

N.B. The three countries with the biggest populations in each sub-region are listed below:

- Africa D – Nigeria, Algeria, and Ghana.
- Africa E – Ethiopia, Congo, and South Africa.
- America A – United States, Canada, and Cuba (all the countries in region).
- America B – Brazil, Mexico, and Colombia.
- America D – Peru, Ecuador, and Guatemala.
- Euro A – Germany, France, and United Kingdom.
- Euro B – Turkey, Poland, and Uzbekistan.
- S.E. Asia B – Indonesia, Thailand, and Sri Lanka (all countries in region).
- S.E. Asia D – India, Bangladesh, and Myanmar.
- W. Pacific A – Japan, Australia, and Singapore.
- W. Pacific B – China, Vietnam, and Philippines.

Extracted from: James et al. [1].
2.1.2 Overweight/Obesity in Children

The problem of overweight/obesity appears to be affecting children and adolescents as well as in adults. The prevalence of obesity among children and adolescents in the developed world and much of the developing world is high and continues to increase[2]. For example, in the US, the percentage of children and adolescents who are overweight has more than doubled in the past 30 years. Approximately 11% of children and adolescents in 2001 were classified as overweight or obese[30]. A more recent study has indicated that the prevalence of overweight/obesity could be as high as 35%[31]. In the UK children by age 8 years were found to have a median body weight of 52 kg, which compared with the age-, gender- and height-matched UK reference population in 1990[32], placed them >20 kg above the mean weight[33]. In Australia, obesity and overweight levels in children were reported to be between 19% and 23%[34]. Furthermore, comparisons with surveys during the 1990s suggest that in Australia, Canada and parts of Europe, prevalence of childhood overweight has increased by 1% of the entire child population each year from 1970-2000. Paediatric obesity in New Zealand is just as alarming as in the other countries and this issue is illustrated by the 2002 National Children’s Nutrition Survey finding, showing that 1 in 10 youngsters aged 5 to 14 years were considered to be obese, and a further 20% were classified as overweight[35]. Compared with the prevalence in 1989, these figures were shown by Turnbull et al[36] to be 2.2 and 3.8 times greater for overweight and obesity respectively.

In developing countries, especially those undergoing rapid socio-economic and nutrition transitions, there is a shift from under- to over-nutrition problems, causing these countries to face the double burden of malnutrition and overweight/obesity. For example, in Brazil between 1974-1997, the combined prevalence of overweight and obesity among 6-17 year old young people has increased dramatically from 4.1% to 13.9%. This is accompanied by a decreasing prevalence of underweight from 14.8% to 8.6%[37]. Similar trends have been observed among urban children in China, where the combined prevalence of overweight/obesity climbed from 7.7% to 12.4% between 1991-1997, while prevalence of underweight dropped from 12.4% to 10.0%[37]. In contrast, in rural areas in China where socio-economic transitions occurred less, the weight status of the population appears to have remained stable with 1997 prevalence for overweight (6.4%) and underweight (13.9%) little changed from 1991[37]. Indeed, as Lobstein et al[2] aptly put it –
‘Overweight is high among the poor in rich countries, and the rich in poorer countries.’
2.1.3 Overweight/Obesity in Preschool Children

Preschool children have long been perceived as highly physically-active, ‘supercharged dynamos’. As a result of which, these younger children have been widely believed to be protected from overweight/obesity[6]. However, growing evidence suggests that this is not necessarily the case. Even among preschool children, it is clear from recent studies that the prevalence of overweight/obesity has increased markedly across the developed world, and even some countries of the developing world[2, 38-41].

Two independent reports representing separate regions in Canada estimated the prevalence of obesity among 2 to 5 year old children at 8-11%[42-43]. In the UK, approximately 10% of children were obese at primary-school entry[44]. In Australia, the prevalence of overweight preschoolers has risen to 17%, from about 10% in the mid 1980s[45]. In New Zealand, although direct evidence of the prevalence of overweight/obesity in preschool children is not available, the recent 2006 New Zealand Health Survey found that among children between 2 to 14 years of age, 1 in 5 people were overweight and 1 in 12 were considered to be obese[46]. Compared to the 2002 New Zealand Health Survey, there has been no change in the average body mass index (BMI) for children aged 5-14 years.

A report from the Division of Nutrition and Development, WHO, has provided an update on the prevalence of overweight in developing countries. De Onis and Blossner[47] analysed the cross-sectional data from the WHO Global Database on Child Growth and Malnutrition[48]. This database was established to describe and monitor the global magnitude of nutritional problems including malnutrition and overweight/obesity in young people. In their study, 160 national nutrition surveys from 94 developing countries in Africa, Asia and Latin America, conducted between 1985 and 1998 were analysed. For 38 countries, more than one data point was available and trends in overweight for these countries were estimated. A trend was classified as rising if the change per year was ≥0.1%, falling if it was ≤0.1%, and static if it was between these 2 cutoffs. Overall, it was estimated that 3.3% (or 17.5 million) of preschool children were overweight in developing countries in 1995. The estimated prevalence of overweight by regions were: Latin America and the Caribbean (4.4%), Africa (3.9%) and Asia (2.9%). When the statistics are broken down by country, the overweight prevalence varied across a wide range. In categorical terms, 74 of the 94 developing countries were considered to be low prevalence (<5.0%) and 20 countries were considered to be moderate prevalence (5.0%-10.0%).
Only 2 countries (Kiribati, Uzbekistan) had rates >10% (Figure 2). By the United Nations sub-regions\(^{[48]}\), the highest prevalence of overweight in children was in North Africa (8.1%), driven mainly by Algeria (9.2%), Egypt (8.6%), and Morocco (6.8%). Southern Africa has the second highest overweight prevalence (6.5%), mainly because of South Africa (6.7%). The lowest prevalence of overweight were in south-central Asia (2.1%), followed by south-eastern Asia (2.4%) and western Africa (2.6%). These latter three regions, unsurprisingly, also suffered the highest rate of wasting (described as low weight-for-height in children\(^{[21, 49]}\)). Trends in overweight were estimated for a total of 38 countries across the developing world, which showed that 14 countries had no obvious change in the prevalence of overweight, 8 countries had a falling trend and 16 countries had a rising trend.

Despite much of the world now facing the ever increasing problem of overweight, in many developing countries undernutrition is also a major public health burden. In fact, the overall prevalence of wasting in preschool children in developing countries remains high (9.4%) and affects >50 million children. In the same study by De Onis & Blössner\(^{[47]}\), 48 of the 94 countries had higher prevalence of wasting than of overweight and the prevalence of wasting was generally higher than those of overweight. For comparisons, 45 countries had wasting rates >5%, whereas 21 countries had overweight rates >5%. Similarly, only 2 countries had overweight rates >10%, whereas 18 countries had wasting rates >10%.

On balance, it is strongly evident that the child population is over-sizing across the developed world and the overweight individuals are becoming ever heaves\(^{[50]}\). In the population of preschool children in the developing world, some countries are starting to have worrisome prevalence of overweight, however undernutrition remains also a major nutrition problem. Therefore for much of the developing countries focus should remain on sustaining proper growth and development for preschool children. However, more countries have shown a rising trend of overweight prevalence than otherwise, reflecting the rapid changes in dietary patterns and lifestyles occurring in these countries\(^{[51]}\). Continued monitoring of the two ends of weight-distribution therefore is warranted to permit timely preventative measures to be implemented, when required. For this purpose it is essential that survey data be analysed systematically in a standard format to allow comparisons over time and across countries.
Figure 2. Weight-for-height distribution of preschool children in 94 countries.

Extracted from: De Onis and Blössner[47].
CHAPTER 2.2: OVERWEIGHT/OBESITY - ITS MULTI-FACETED CONSEQUENCES

2.2.1 Introduction

Prompted by the growing prevalence of overweight/obesity, the scientific community has been studying this topic aiming to identify its aetiology, clarify its prevalence across the different regions of the world and accounting how these conditions have impacted the world. There are various ‘life-style-related diseases’ which were once thought to only encumber adults such as coronary artery disease, type 2 diabetes and obstructive sleep apnoea. Over the past 20 years, these diseases have begun to emerge also in the domain of paediatric medicine, suspiciously coincidentally with the increasing childhood overweight/obesity. Indeed, the associations are becoming clearer between overweight/obesity and many of the newly emerged health problems in young people. The International Association for the Study of Obesity, from the IOTF in 2004\textsuperscript{[2]} reviewed the costs of childhood obesity, and summarised their findings under the headings of physical, psycho-social and economic consequences.

2.2.2 Physical Consequence of Overweight/Obesity

Clinical studies of obese children have suggested a range of health conditions that obese children are at greater risk from\textsuperscript{[52]}. As can be seen from Table 1, the impact of obesity is systemic and many conditions have the potential to cause life-long consequences. In particular, conditions affecting the cardiovascular, endocrine (namely type 2 diabetes) and pulmonary systems have been emphasised\textsuperscript{[2]}.

2.2.2.1 Pulmonary diseases

Overweight youth may have an elevated risk of developing ‘sleep-associated breathing disorder’, which is a condition consisted of narrowing of airways, shortness of breath, reduction in deep breathing and apnoea. For example, studies have found abnormal sleep patterns between 33% and 94% of children with severe obesity, due to episodes of apnoea, hypopnea and excessive arousals or abnormalities in gas exchange\textsuperscript{[53-54]}. 
<table>
<thead>
<tr>
<th>Table 1. Physical consequences of childhood and adolescent obesity.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extracted from: Lobstein[2]</td>
</tr>
<tr>
<td><strong>Cardiovascular</strong></td>
</tr>
<tr>
<td>Hypertension</td>
</tr>
<tr>
<td>Dyslipidaemia</td>
</tr>
<tr>
<td>Fatty streaks</td>
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<tr>
<td>Left ventricular hypertrophy</td>
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<tr>
<td><strong>Endocrine</strong></td>
</tr>
<tr>
<td>Insulin resistance/impaired glucose tolerance</td>
</tr>
<tr>
<td>Type 2 diabetes</td>
</tr>
<tr>
<td>Menstrual abnormalities</td>
</tr>
<tr>
<td>Polycystic ovary syndrome</td>
</tr>
<tr>
<td>Hypercorticism</td>
</tr>
<tr>
<td><strong>Pulmonary</strong></td>
</tr>
<tr>
<td>Sleep apnoea</td>
</tr>
<tr>
<td>Asthma</td>
</tr>
<tr>
<td>Pickwickian syndrome</td>
</tr>
<tr>
<td><strong>Gastroenterological</strong></td>
</tr>
<tr>
<td>Cholelithiasis</td>
</tr>
<tr>
<td>Liver steatosis / non-alcoholic fatty liver</td>
</tr>
<tr>
<td>Gastro-oesophageal reflux</td>
</tr>
<tr>
<td><strong>Neurological</strong></td>
</tr>
<tr>
<td>Idiopathic intracranial hypertension (e.g. pseudotumour cerebri)</td>
</tr>
<tr>
<td><strong>Orthopaedic</strong></td>
</tr>
<tr>
<td>Slipped capital epiphyses</td>
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<tr>
<td>Blount’s disease (tibia vara)</td>
</tr>
<tr>
<td>Tibial torsion</td>
</tr>
<tr>
<td>Flat feet</td>
</tr>
<tr>
<td>Ankle sprains</td>
</tr>
<tr>
<td>Increased risk of fractures</td>
</tr>
<tr>
<td><strong>Other</strong></td>
</tr>
<tr>
<td>Systemic inflammation/raised C-reactive protein</td>
</tr>
</tbody>
</table>
Although the gas exchange abnormalities were usually mild, severe obstructive sleep apnoea was reported in 5% of children with severe obesity\[53\]. Obstructive sleep apnoea is known to cause troubling disturbances, particularly with difficulties in learning and memory function which if not treated could lead to disabling life-long consequences in children\[55\]. Furthermore obesity-linked hypoventilation syndrome has been shown to confer a significantly higher risk of developing pulmonary embolism and sudden death in children\[56-57\]. Childhood overweight has also been shown to be associated with an increased prevalence of asthma\[58-61\], irrespective of age, gender and ethnicity.

2.2.2.2 Type 2 diabetes

The prevalence of type 2 diabetes among young people has been reported to have markedly increased over the two decades from early 1980s. For example, a study found that in Cincinnati, the prevalence of adolescent type 2 diabetes has markedly increased from 0.7 to 7.2 cases per 100,000 population in the period from 1982 to 1994\[62\]. Such a rising trend has been noted at other places too\[63\], even among preadolescent children\[64\]. When compared with the prevalence of type 1 diabetes, a review by the American Diabetes Association has suggested that as many as 45% of diabetic cases among the paediatric population are the type 2 diabetes form\[65\].

Alarmingly, among adolescents with type 2 diabetes, excess body weight (BMI ≥85th percentile) was found in between 80-90% of cases\[64, 66\], while among children with type 1 diabetes, excess body weight was found in 25% of cases\[64\]. Alternatively when prevalence of impaired glucose tolerance and type 2 diabetes was sought among US children and adolescents who had obesity (BMI >95th percentile), estimates were 25% (younger children) and 21% (adolescents) for impaired glucose tolerance and 4% overall met the criteria for type 2 diabetes\[67\]. Similar figures in Europe seemed slightly less pressing, with estimates ranged from 5.0-14.9% for impaired glucose tolerance and <0.2%-1.9% for type 2 diabetes\[68\]. It should be noted that diagnosis of type 2 diabetes among children and adolescents is difficult as the majority of patients are asymptomatic or present atypically rather than with the classic polyuria, polydipsia and weight loss\[64\]. The prevalence presented by the studies may have been conservative estimates.
2.2.2.3 Cardiovascular diseases

Studies investigating cardiovascular risk factors in relation to overweight/obesity have been no less attentive. The cluster of cardiovascular risk factors commonly seen in adulthood – including hypertension, hypertriglyceridaemia, low HDL cholesterol and hyperinsulinaemia – also known as the metabolic syndrome, and their prevalences in youth with overweight/obesity have been documented by many. Most of the findings have shown a strong association with each of the risk factors\(^{69-75}\). For example, a longitudinal study followed a cohort of 191 participants from adolescence to 27-31 years of age compared the cardiovascular risk factors between non-overweight participants and participants with adolescent-onset adult overweight. The overweight group showed increased prevalence of hypertension (by 8.5-fold), higher total serum cholesterol (2.4-fold), higher LDL serum cholesterol (3-fold) and lower HDL serum cholesterol (8-fold)\(^{76}\). In another Finnish longitudinal study where prevalence of metabolic syndrome was compared between weight status from childhood to adults, obese adults who were also obese as children had a prevalence of 28%, compared with obese adults who were not obese in childhood (10%)\(^{74}\). Metabolic syndrome has actually been reported in paediatric patients. For example, the 3\(^{rd}\) US National Health and Nutrition Examination Survey has shown the overall prevalence of metabolic syndrome to be 4.2%, rising from 0.1% of normal weight adolescents to 6.8% in adolescents with BMI in the 85\(^{th}\)-95\(^{th}\) percentile, and to the menacing 28.7% among obese adolescents with BMI in the 95\(^{th}\) percentile and above\(^{69}\). In their book published by Cambridge Press, Freedman \textit{et al}\(^{77}\) found that even in children aged 5-10 years, positive relationships exist between hypertension, hyperinsulinaemia, dyslipidaemia, and high BMI (≥85\(^{th}\) percentile) (Figures 3-5).
Figure 3. Proportion of 5-10 year old children with raised (≥95th percentile) systolic and diastolic blood pressure by BMI percentiles. 
Extracted from: Freedman et al[77].

Figure 4. Proportion of 5-10 year old children with raised (≥95th percentile) insulin levels by BMI percentiles. 
Extracted from: Freedman et al[77].

Figure 5. Proportion of 5-10 year old children with raised triglycerides (TG >130 mg.dL⁻¹), low-density-lipoprotein cholesterol (LDL >130 mg.dL⁻¹) and lowered high-density-lipoprotein cholesterol (HDL <35 mg.dL⁻¹), by BMI percentiles. 
Extracted from: Freedman et al[77].
2.2.3 Psycho-Social Consequences of Overweight/Obesity

Stigmatisation of children and adolescents who are overweight or have obesity, especially by the children’s peers, has had a long history of documentation dating back to as early as the 1960s\[78\]. Studies conducted in the countries with western cultures have reported stigmatisation in various forms including that obese body types being connotative of negative characteristics like – lazy, sloppy, denying, ugly, dirty, and stupid\[78-81\], that children were reluctant to share in games or activities with their overweight peers\[82\]; and that obesity is ranked ‘the least likable’ among a range of handicaps\[83\]. Another study has actually observed that the number of friends reported by overweight girls was less compared to non-overweight girls\[84\], however a similar study among 9 year old girls in the UK did not find such differences\[85\]. Although it has become increasingly clear that overweight/obesity should be regarded as a complex and multi-factorial disorder\[86-89\], evidence exists that the negative stereotyping of a child with obesity has not softened\[82, 90\]. Given the discrimination experienced by obese children, it is likely that they would suffer some degree of psychological distress. The effect of overweight/obesity on children’s self-esteem, mood and anxiety level has been studied. The evidence has shown varying results. Measures of effect on self-esteem have shown a weak association with low self-esteem by some studies\[85, 91-94\], while some other studies have not observed such an association\[57, 95\]. Studies on depression once again have shown varying results, ranging from no evidence that obesity increases risk of depression\[96\], to observing a weak association between obesity and suicidal ideation\[97\], to having feelings of hopelessness and suicidal attempts in overweight adolescent girls\[81\] (results for boys did not show statistically significant association), and to having increased suicidal ideation and attempts among overweight adolescents of both sexes\[98\].

It is worth noting that in different cultures a more acceptable perception of overweight/obesity exists. For example, in Mexico it is a strong sign of loving parental care to have food treats for children and the fatter the children are the healthier they are perceived to be\[99\]. Obesity-related psycho-social problems that were seen in western cultures such as stigmatisation and peer rejection were not found in Mexican children who had obesity\[99\], indicating that family and peer attitudes contribute significantly to causing psycho-social distress encumbering overweight children.
2.2.4 Economic Costs of Paediatric Overweight/Obesity

With more people across the world becoming dangerously heavy, the spectrum of overweight conditions especially obesity and its related physical and psycho-social conditions will demand a bigger share on the investment into health services. Obesity has been estimated to already account for 2-7% of some developed countries’ total health care costs\(^{[3]}\). For example, a study estimated the health care costs of obesity in New Zealand by multiplying the cost of non-insulin dependent diabetes, coronary heart disease, hypertension, gallstone disease, post-menopausal breast cancer and colon cancer by their respective population attributable fraction for obesity (values which quantify the degrees of contribution obesity has to the specified diseases). The estimate of the health care costs due to these conditions was NZ$135 million which represented about 2.5% of total health care costs\(^{[100]}\). Another study used the US hospital discharge diagnoses from patients aged between 6-17 years to compare the rates of obesity-related diagnoses in 1997-1999 with those about two decades earlier in 1979-1981. Predictably, they found a rising trend of rates of obesity-related diagnoses overall, which include asthma (5.9Æ8.1%), sleep apnoea (0.2Æ0.8%), type 2 diabetes mellitus (1.4Æ2.4%) and gall bladder disease (0.3Æ0.6%)\(^{[101]}\). As a whole, the rates of admission have nearly doubled over the two decades. In addition, the cost of case-by-case treatment of overweight-related problems have increased (due to lengthened in-patient stay and increased cost per episode for medical treatment), so that the final increase in economic cost was estimated to be from US$35 million per year (0.43% of total hospital costs) to US$127 million per year (1.70% of total hospital costs) between the years 1980-2000\(^{[101]}\). This figure was estimated after adjustment for inflation.
2.2.5 Summary

The worsening global epidemic of overweight/obesity is very alarming. Furthermore, there is much concern over tracking of obesity from childhood to adulthood and its contribution to adult obesity related morbidity and mortality\(^{[102-103]}\). It has been readily observed by longitudinal studies that overweight/obesity during childhood has high potential to persist into adulthood\(^{[104-105]}\). Whilst recognising that the treatment of obesity is also an important approach that needs to be addressed concurrently with prevention approaches, prevention of obesity is likely to be more cost effective than treatment\(^{[3]}\). This is particularly important in children for two indications: primary prevention and prevention of overweight children from carrying their excess weight into adulthood. In fact, it has been suggested that the prevention of childhood obesity is the only viable, enduring, cost-effective solution to the obesity epidemic\(^{[106]}\).
CHAPTER 2.3: THE ROLE OF PHYSICAL ACTIVITY IN CHILD HEALTH

2.3.1 Introduction

Investigations into the strategies to tackle the global overweight issue have been an increasing focus over the past two decades. The discussion on the aetiology of overweight/obesity is by no means a simple one because determinants span across many aspects of living, such as PA, diet and the various obesogenic environments. There is complex interaction between the determinants for each of the aspects and each case of overweight/obesity involved heterogeneous aetiology\(^{[106-107]}\). However, among the proposed targets for intervention, PA is a common theme that has been highlighted internationally as beneficial for weight control. For example, a scientific symposium in year 2000 sponsored by Health Canada and the US Centers for Disease Control and Prevention which reviewed available randomised controlled trials (RCT) concluded that a linear dose-response relationship between the quantity of PA and the amount of weight loss is evident based on studies of \(\leq 16\) week duration when diet is controlled\(^{[4]}\). This linear relationship was considered to be having a category A evidence base using the National Institutes of Health evidence criteria\(^{[108]}\). Category A means that evidence is from endpoints of a large volume of well-designed RCTs involving substantial numbers of participants (or trials that depart only minimally from randomisation) that provide a consistent pattern of findings in the population for which the recommendation is made. Considering the long-term relationship between PA and weight status, the Panel also concluded that increased levels of PA are associated with the prevention of weight gain (Category C, i.e. evidence is from outcomes of uncontrolled or non-randomised trials or from observation studies), however the nature of the dose-response relationship requires further clarification\(^{[4]}\). In addition, PA is associated with numerous other major health benefits including reduction in the incidences of all-cause mortality, cardiovascular disease, type 2 diabetes mellitus as well as improved physical function and mental health in general\(^{[4-6, 8]}\).
2.3.2 The Role of Physical Activity in School-aged children

In school-aged children, PA has also been considered to confer similar benefits to those seen in adult studies. Many studies including RCTs have reported the beneficial effects of PA in children on the indicators of cardiovascular health\[^7,\ 109-121\], skeletal health\[^122-131\] and mental health\[^132-141\]. In relation to glucose metabolism, PA intervention programmes have improved insulin resistance in both children with or without obesity\[^142\]. Where weight loss was achieved, level of hyperinsulinaemia was decreased\[^143\], although insulin level is still above the normal range\[^144\]. With regard to weight status, Strong et al\[^7\], in a systemic review on the effects of regular PA on several health outcomes in school-aged youth concluded that programmes of moderately intense exercise of 30 to 60 minutes in duration, 3 to 7 days per week led to a reduction in total body and visceral adiposity in overweight children and adolescents\[^145-146\]. However it is worthwhile noting that similar programmes may be less effective in normal weight youth\[^146-148\] and longer, more intensive sessions (>80 minutes/day) may be required to confer beneficial changes to weight-related outcomes in normal weight youth\[^115,\ 149\] (Table 2).

Although PA seems to be beneficial in many ways in adults as well as children and adolescents, it is likely that the risk of injury or accident could be increased. These risks need to be weighed up against benefits. Injuries are a major cause of disabling morbidity and mortality in children and a large proportion of injuries occur in relation to some forms of PA\[^150\]. For example, injuries from sport and recreational activities, such as cycling, skateboarding, and playground use make up a major proportion of all visits to emergency departments in Australian children aged from birth to 14 years\[^151\]. The 2001 Australian National Health Survey estimated the prevalence of acute and chronic injuries among young people from birth to 14 years of age. Among the 21% of young people who reported having acquired an injury in the previous four weeks, 74% were injured during participation in sports or leisure activities\[^152\].
<table>
<thead>
<tr>
<th>Study</th>
<th>Sample</th>
<th>Length</th>
<th>Frequency</th>
<th>Exercise</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gutin, Barbeau et al [145]</td>
<td>13-16 yo, N=80 adolescents having obesity</td>
<td>8 mths</td>
<td>≥2×/week</td>
<td>Targeted AEE at ~1045 kJ (250 kcal)/session regardless of intensity of PA. Individualised PA sessions (mean durations=29-43 minutes), programme involved treadmills, cycles, rowers, steppers, aerobics, basketball, badminton, kickball, and aerobic slide.</td>
<td>Meaningful favorable changes in % body fat (p=0.001), and visceral adipose tissue by (p=0.029), by about 3.8 and 4 fold respectively.</td>
</tr>
<tr>
<td>Owens, Gutin et al [146]</td>
<td>7-11 yo, N=74 children with obesity</td>
<td>4 mths</td>
<td>5×/week, 40 min/session</td>
<td>Controlled physical training, at a mean heart rate of 157 beats/min. The estimated EE per training session was 925±201 kJ.</td>
<td>Physical training group compared with control group had significantly declined % body fat (-2.2%) (p&lt;0.01), total fat mass (-3.1%) (p&lt;0.01), subcutaneous abdominal adipose tissue (-16.1%) (p&lt;0.05); and significantly increased fat-free mass (+6.1%) (p&lt;0.05).</td>
</tr>
<tr>
<td>Linder, DuRant et al [147]</td>
<td>11-17 yo, N=50 non-obese white males</td>
<td>8 wks</td>
<td>4 day/week, 30 min/day</td>
<td>Progressive aerobic exercise programme.</td>
<td>No difference in serum lipid and lipoprotein levels after 8 weeks between the physical conditioning group and control group.</td>
</tr>
<tr>
<td>Rowland, Martel et al [148]</td>
<td>10-12 yo, N=31 non-obese children</td>
<td>13 wks</td>
<td>3 day/week, 25 min/session</td>
<td>Aerobic activities with training intensity assessed by HR monitors.</td>
<td>No significant changes were observed in any of the blood lipid levels between the control and training periods training period.</td>
</tr>
<tr>
<td>Eliakim, Makowski et al [115]</td>
<td>16±0.7 yo, N=38 non-obese sedentary children</td>
<td>5 wks</td>
<td>N/A</td>
<td>Endurance-type exercise training.</td>
<td>No change in body weight, lipid levels in either control or training groups. Physical training led to small but significant reductions in thigh fat (-4.6±1.5%, p&lt;0.03) and subcutaneous abdominal adipose tissue % (1.7±0.8%, p&lt;0.02). There was no change in intra-abdominal adipose tissue.</td>
</tr>
<tr>
<td>Barbeau and Litaker [149]</td>
<td>9.6±0.9 yo, N=112 non-obese females</td>
<td>10 mths</td>
<td>N/A</td>
<td>PA intervention not otherwise specified.</td>
<td>Compared to the control group, the intervention group had: a smaller increase in fat mass (1.1±2.1 vs 2.2±2.7 kg, p=0.01) and a decrease in % body fat (-1.1±3.4 vs 0.5±3.4%, p=0.01).</td>
</tr>
</tbody>
</table>
2.3.3 The Role of Physical Activity in Preschool children

The health effects of PA in preschool children have received relatively small amounts of study\textsuperscript{[107, 153]} partly due to the difficulty in determining their sporadic and intermittent nature of PA (or more accurately defined as play) and the previous conception that children of this age group are well-protected from the overweight/obesity crisis\textsuperscript{[6]}. Unlike in adults and older children, the relationship between PA and some of the well-recognised benefits such as cardiovascular or weight-related benefits, are less clear in preschool children. For example, based on outcomes from 6 non-randomised trials and observational studies reviewed by Okely \textit{et al}\textsuperscript{[154]} there is a positive association (supported by between 60-100\% of findings across the studies reviewed) between PA and blood pressure, an inconsistent association with blood lipid profiles and no association with cardio-respiratory fitness. On the other hand, similar to older children, intervention studies have consistently demonstrated benefits from structured PA sessions with motor development and musculoskeletal health\textsuperscript{[154]}. In another review of RCTs, Timmons \textit{et al}\textsuperscript{[155]} found that PA sessions of 20 min/day, 3 times/week employed by most of the intervention studies appeared to be capable of improving bone properties, motor skills and aerobic fitness. They also found within the limited evidence available that as little as an additional 20 minutes of aerobics-type activity can improve aspects of self-esteem and promote long-term social functional benefits\textsuperscript{[155]}. However it is important to note that the conclusions from this review rest on very few studies with relatively small numbers of participants, making the evidence level less robust\textsuperscript{[155]}. In fact the literature concerning the effects of PA in preschool children contains many studies limited by small sample size, use of non-objective measures of exposure to PA, inadequate control for social, growth and developmental factors and the overwhelming majority of studies are of cross-sectional design\textsuperscript{[107]}.

With regard to adiposity-related outcomes, results from PA intervention studies in preschool children have been inconsistent. There have been a few studies reporting having a lower BMI and BMI-Z score in the intervention group compared to control group at year 1 and 2 follow-ups\textsuperscript{[155-156]}, while some reported having no effect on BMI-Z score relative to control groups\textsuperscript{[157-158]}. However when the association of PA with adiposity-related outcomes is examined by following a cohort of children over a long period, an inverse relationship between PA level and adiposity was consistently demonstrated. Several studies have found that baseline PA level was a significant predictor of change in the BMI of 3-5 year old children over the next 2 years\textsuperscript{[155, 159]}.
Likewise, Moore et al.[160] found that compared to active children, those who were inactive at age 4 years were 2.6 times more likely to increase their triceps skin fold measurement over a ~2.5 year follow-up[160]. It should be noted that weight gain in preschool children is a normal outcome, and despite that, the rate was less in the groups who were more active at baseline reducing chance of such measures to become excess, weight gained by children who were more sedentary may still be within the normal range[154].

In summary, although regular participation in PA has been established as a beneficial intervention in improving the health and weight status in adults, adolescents and school-aged children, its effects among preschool children is less clearly understood. The evidence base on the health benefits of PA in preschool children needs to be strengthened and significantly more research is required to investigate the effect of PA intervention on weight-related measures.
CHAPTER 2.4: CURRENT RECOMMENDATIONS ON PHYSICAL ACTIVITY LEVEL

2.4.1 Physical Activity Guidelines for Youth

The previous chapter has introduced the importance of PA for children for its association with a plethora of physiological and psycho-social benefits and its potential for maintaining a healthy body mass. Consequently, there has been great interest in identifying the amount of PA that is associated with desirable health outcomes and a number of medical, public health, and professional organisations have issued recommendations related to PA and SB in children of all age groups. Existing guidelines have been recently systemically reviewed by Janssen\textsuperscript{161} (Table 3). There have been more guidelines published for school-aged children than is shown in (Table 3), however, the recommendations made by these guidelines have been in general terms without specific recommendation of the quantity of PA. The latter studies were therefore not included in the review by Janssen\textsuperscript{161}.

Before 1998 the PA guidelines for children were largely comparable with PA guidelines for adults, which typically recommended about 30 minutes of accumulated PA on most or all days of the week\textsuperscript{162-163}. In 1998 the first set of PA guidelines based specifically on studies of children was developed and published by the UK Health Education Authority\textsuperscript{164}. Since then a number of other organisations have contributed to developing the evidence base of PA recommendations for children. The recommendations were mostly consistent in terms of the quantity of PA participation. The guidelines have collectively specified (with the only exception being the Canadian guidelines by Health Canada and the Canadian Society for Exercise Physiology\textsuperscript{165-166}) that children and youth should participate in at least 60 minutes of MVPA on a daily basis. A recent large-scale systemic review by an expert panel under a contract with the Centers for Disease Control and Prevention concluded that for school-aged children (6-18 year olds), evidence is strong for several beneficial effects from health and daily participation in 60 minutes of MVPA\textsuperscript{7}.
Table 3. Existing physical activity guidelines for school-aged children and youth.
Modified from: Janssen\cite{161}.

<table>
<thead>
<tr>
<th>Organisation</th>
<th>Title of recommendation</th>
<th>Year</th>
<th>Age range</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>American College of Sports Medicine\cite{167}</td>
<td>Opinion statement on physical fitness in children and youth</td>
<td>1988</td>
<td>Children and youth</td>
<td>Obtain 20-30 minutes of vigorous exercise each day.</td>
</tr>
<tr>
<td>International Consensus Conference on Physical Activity Guidelines for Adolescents\cite{168}</td>
<td>Physical activity guideline for adolescents: consensus statement</td>
<td>1994</td>
<td>11-21 year old</td>
<td>Be physically active daily, or nearly daily, as part of play, games, sports, work, transportation, recreation, physical education, or planned exercise; engage in ≥3 sessions/week of moderate to vigorous activities that last ≥20 minutes.</td>
</tr>
<tr>
<td>US National Institutes of Health\cite{169}</td>
<td>Consensus development panel on physical activity and cardiovascular health</td>
<td>1995</td>
<td>All</td>
<td>Accumulate 30 minutes of moderate PA on most, preferably all, days of the week.</td>
</tr>
<tr>
<td>US Surgeon General\cite{8}</td>
<td>Physical activity and health</td>
<td>1996</td>
<td>≥2 year old</td>
<td>Accumulate 30 minutes of moderate PA on most, preferably all, days of the week.</td>
</tr>
<tr>
<td>UK Health Education Authority\cite{164}</td>
<td>Young people and health-enhancing physical activity: evidence and implications</td>
<td>1998</td>
<td>Children and Youth</td>
<td>Participate in PA that is of at least a moderate intensity for an average of 1 h/day; participate in PA that enhance and maintain strength in the musculature of the trunk and upper arm girdle ≥2 day/week; the above recommendation should be met by participating in developmentally appropriate activities.</td>
</tr>
<tr>
<td>Australia Department of Health and Ageing\cite{170}</td>
<td>National physical activity guidelines for Australians</td>
<td>1999</td>
<td>5-18 year old</td>
<td>At least 60 minutes, and up to several hours, of moderate to vigorous PA every day; limit screen time ≤2 h/day.</td>
</tr>
<tr>
<td>American Cancer Society\cite{171}</td>
<td>Guidelines on nutrition and physical activity for cancer prevention</td>
<td>2002</td>
<td>Children and youth</td>
<td>Engage in ≥60 min/day of moderate to vigorous PA at least 5 day/week.</td>
</tr>
<tr>
<td>Organisation</td>
<td>Title of recommendation</td>
<td>Year</td>
<td>Age range</td>
<td>Recommendation</td>
</tr>
<tr>
<td>----------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------</td>
<td>-------</td>
<td>-------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Health Canada and the Canadian Society for Exercise Physiology (^{[165-166]})</td>
<td>Canada’s physical activity guide for children and youth</td>
<td>2002</td>
<td>6-14 year old</td>
<td>Increase time currently engaged in PA by at least 30 min/day (in periods of at least 5-10 minutes), progressing to ≥90 min/day more PA; the 90 min/day increase in PA should include both moderate (60 minutes) and vigorous (30 minutes) activities; decrease time spent doing sedentary activities (TV, video games, internet), initially by 30 min/day, eventually by ≥90 min/day.</td>
</tr>
<tr>
<td>Weight Realities Division of the Society for Nutrition Education (^{[172]})</td>
<td>Guidelines for childhood obesity prevention programmes</td>
<td>2003</td>
<td>Children</td>
<td>Be active for at least 60 min/day; limit screen time to &lt;2 h/day and replace with more active activities.</td>
</tr>
<tr>
<td>US National Association for Sports and Physical Education (^{[173]})</td>
<td>Guidelines for appropriate physical activity for elementary school children</td>
<td>2003</td>
<td>5-12 year old</td>
<td>Accumulate at least 60 minutes, and up to several hours, of age-appropriate PA on all, or most days of the week; daily accumulation should include moderate and vigorous PA, with the majority being intermittent in nature.</td>
</tr>
<tr>
<td>World Health Organisation (^{[174]})</td>
<td>Non-communicable Disease Prevention and Health Promotion</td>
<td>2003</td>
<td>All</td>
<td>Minimum of 30 minutes of cumulative moderate PA daily. For children and young people an additional 20 minutes of vigorous PA 3 times a week.</td>
</tr>
<tr>
<td>US Department of Health and Human Services and US Department of Agriculture (^{[175]})</td>
<td>Dietary guidelines for Americans</td>
<td>2005</td>
<td>Children and youth</td>
<td>Accumulate ≥60 minutes of PA on most, preferably all, days of the week.</td>
</tr>
<tr>
<td>Divisions of Nutrition and Physical Activity and Adolescent and School Health of the US Centers for Disease Control (^{[7]})</td>
<td>Evidence based physical activity for school-aged youth</td>
<td>2005</td>
<td>6-18 year old</td>
<td>Participate in ≥60 min/day of moderate to vigorous PA; activities should be developmentally appropriate, enjoyable, and involve a variety of activities.</td>
</tr>
<tr>
<td>Nordic Council of Ministers (^{[176]})</td>
<td>Nordic Nutrition Recommendations</td>
<td>2005</td>
<td>Children and youth</td>
<td>Minimum of 60 minutes of activity should include both moderate and vigorous intensity and can probably be divided into shorter intervals of PA during the course of the day</td>
</tr>
</tbody>
</table>

N.B. Guidelines are listed in chronological order of release.
2.4.2 Physical Activity Recommendations for Preschoolers

2.4.2.1 Introduction
Until recently the PA guidelines have focused on school-aged children and adolescents (6-18 years of age). This was considered to be partly due to the relatively scarce research documenting the health effects of PA in preschool children. Nevertheless, the National Association for Sport and Physical Education (NASPE) in 2002 has attempted to formulate PA guidelines for children aged birth-5 years. The NASPE Active Start Guidelines from North America are the only quantitative guidelines for children younger than 5 year old\textsuperscript{[177]}. Based on the three early childhood developmental periods relating to PA, namely infancy, toddler, and preschool periods, different types of activities as well as the prescribed amounts were recommended for infants, toddlers and preschool children. Table 4 provides an overview of the 5 proposed guidelines for preschool children:

<table>
<thead>
<tr>
<th>Guideline</th>
<th>Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Preschoolers should accumulate at least 60 minutes daily of structured PA</td>
</tr>
<tr>
<td>2</td>
<td>Preschoolers should engage in at least 60 minutes and up to several hours of daily unstructured PA and should not be sedentary for more than 60 minutes at a time except when sleeping</td>
</tr>
<tr>
<td>3</td>
<td>Preschoolers should develop competence in movement skills that are building blocks for more complex movement tasks</td>
</tr>
<tr>
<td>4</td>
<td>Preschoolers should have indoor and outdoor areas that meet or exceed recommended safety standards for performing large muscle activities</td>
</tr>
<tr>
<td>5</td>
<td>Individuals responsible for the well-being of preschoolers should be aware of the importance of PA and facilitate the child’s movement skills</td>
</tr>
</tbody>
</table>

Table 4. National Association for Sports and Physical Education guidelines for physical activity in preschool children.

Studies wherein PA patterns of young children were continuously monitored using accelerometers have shown that when preschool children are active, movement is characterised by short bursts of activity lasting largely between 5-10 minutes throughout a typical day and the velocity and movement types can vary considerably\textsuperscript{[178-183]}. Therefore it is practical and realistic that PA for preschool
children is recommended in terms of accumulated amount\textsuperscript{[161]}, as described by criterion one in the NASPE guidelines. It is unclear of whether there is a rationale for prescribing separate amounts of time for structured and unstructured PA\textsuperscript{[154]}. However it has been recognised that participation in PA should incorporate both aerobic and anaerobic activities in order to provide maximum health benefits\textsuperscript{[7]}. For example, participation in strength-training activities has beneficial effects on muscular strength and bone density while participation in aerobic activities reduces several cardio-respiratory risk factors\textsuperscript{[161]}. Moreover some of the health benefits such as blood pressure, increased bone health and reductions in adiposity are greater with MVPA than lower intensity PA, with further benefits seen in VPA than moderate MPA\textsuperscript{[7]}. Therefore it is advisable to include both moderate and vigorous intensity activities.

2.4.2.2 Limitations with the Guideline

With regard to the NASPE recommendation of 60 minutes of PA for preschool children, the evidence base for preschool children is not strong enough to endorse such a recommendation. Although the review by Timmons \textit{et al}\textsuperscript{[155]} found that as little as an additional 60 min/week of exercise may improve bone properties, aerobic fitness, and motor skills in some children, these findings were based on very few studies with relatively small numbers of participants. Several guidelines have concluded that the scientific evidence is too weak to prescribe a minimum volume of PA for preschoolers\textsuperscript{[154-155, 165-166]}. In addition, researchers have raised concerns that one hour of PA might actually be insufficient to prevent clustering of cardiovascular disease risk factors\textsuperscript{[184]}. For example, in a recent issue of Lancet, the European Youth Heart Study\textsuperscript{[185]} looked at 1,732 randomly selected 9 and 15 year old school children from Denmark, Estonia and Portugal, and observed a graded negative association between clustering of cardiovascular risk factors and PA determined by accelerometry. There was an increased risk in the 3 quintiles of PA of the lower end compared with the most active quintile. Time spent at moderate and vigorous intensity activity (corresponding to a walking speed of around 4 km/h\textsuperscript{[186]}) by participants of the most active quintile was between 116 minutes in 9 year olds and 88 minutes in 15 year olds. Thus it was recommended that PA levels should be higher than 60 minutes and that obtaining 90 minutes of daily PA may be required for children to prevent clustering of cardiovascular disease risk factors\textsuperscript{[185]}. 

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2.4.2.3 Summary of the Qualitative PA Guidelines for Preschool Children

Summing all the evidence available, there are several common key points recommended by the various guidelines:

1. Promotion of PA for preschool children should consider their natural activity patterns, which are typically spontaneous and intermittent. Physical activity should be encouraged and accumulated throughout the day in durations of 5-10 minutes\[155, 161\].

2. Carers (inclusive of parents and day care providers) should encourage preschool children to engage in unstructured play at his or her own pace to develop fundamental movement skills. Participation in developmentally appropriate, structured activities such as tumbling or dancing is a good option if these are guided by qualified, experienced instructors\[155, 187-188\].

3. All preschool children should participate regularly in PA. In particular daily activities should be encouraged by carers (e.g. walking, riding a tricycle or playing at the playground) and the concept of PA as a natural and life-long activity of healthy living should be emphasised\[187-189\].

4. Carers should be encouraged to participate in regular free play and their children with emphasis on fun, playfulness, exploration, and experimentation with their children\[154, 188-190\].

5. Children should be supervised when they participate in PA and importance of safety equipment (e.g. helmets, goggles, sunlight protection) should be emphasised\[154, 187-188\].
CHAPTER 2.5: MEASURING PHYSICAL ACTIVITY IN PRESCHOOL CHILDREN

2.5.1 Introduction

Physical activity is defined as ‘any bodily movement produced by skeletal muscle that results in energy expenditure’ \(^{[191]}\). Energy expenditure (EE) is a physiologic consequence of PA and is directly linked to prevention of overweight/obesity \(^{[15]}\). In relation to PA, EE is specified as either at rest (REE), during activity (AEE) or over a total period of time (TEE). This classification is also used in the definition of intensity of PA by metabolic equivalence (MET). Metabolic equivalent is a widely used physiological concept that expresses energy cost of PA as multiples of resting metabolic rate (RMR), as calculated by the equation \(^{[192]}\):

\[
\frac{\text{AEE}}{\text{RMR}} = \text{MET}
\]

The American College of Sports Medicine has categorised MET into different PA intensity for adults (sedentary: 1-1.5 METs; light: 1.5-3 METs; moderate: 3-6 METs; vigorous >6 METs) \(^{[193]}\), which has been adopted in the paediatric population and used to define thresholds with the various PA measurement tools. Using MET is considered to be advantageous over EE, which is variable between individuals due to other factors as well as PA. For example, ethnicity seems to be important in one study in which white children exhibited significantly higher REE compared with African American children (after adjusting for age, pubertal maturation and body composition) \(^{[194]}\). In another study with adult participants, genotype alone was estimated to influence REE by about 40% \(^{[195]}\). However other studies have also observed no effect from ethnicity on REE, but some effect on TEE and AEE \(^{[196]}\). On balance, EE is a complex variable determined by more than just PA alone and using MET is considered to be an alternative that to some extent buffers the effect of individual variations in EE \(^{[197-198]}\).

Metabolic equivalent has also been commonly described in terms of oxygen consumption. For example, Morris et al \(^{[199]}\) identified MET as the quantity of oxygen consumed by the body from inspired air under resting metabolic conditions with 1 MET equal on average to 3.5 ml oxygen/kg/min. It should be noted however that the
validity of the MET value of 3.5 ml oxygen/kg/min is somewhat unclear[198, 200]. Moreover, this value was derived from adult resting conditions which could create an age-dependent bias if used to interpret MET in children, who tend to have higher oxygen consumption rate than adults[201]. As well as this, the RMR of children is not constant but declines with age from 6 to 3.5 ml oxygen/kg/min[202]. Therefore until a validated standard basal oxygen consumption rate becomes available for children, it may be more appropriate to include measurement of individual RMR in any study design to derive the values of MET.

2.5.2 Physical Activity Measurement

Understanding PA measurement in young children not only allows for examining the health consequences of PA but it would also allow for identification of the group of children at risk from health consequences, monitoring the dose-response relationship between PA and weight-related health constructs and establishing intervention efficacy of the current PA recommendations to ultimately allow for developing a standardised international PA intervention for overweight[203-204]. Over the years efforts to develop a gold standard have resulted in a rich evidence base of studies using a variety of measurement methods to estimate PA and its indicators in young people. For example, the type, duration and frequency of PA have been assessed using proxy-report, direction observation systems or accelerometers, while methods to assess indicators of PA have also been examined such as step count measured by pedometers and heart rate (HR) measured by portable HR monitors.

These methods all have their advantages and disadvantages. Based on how reflective the measurement methods are of PA, Sirard and Pate[205] have categorised them into primary measures (criterion standards), secondary measures and subjective measures (Figure 6). In-depth assessment of the intensity of PA is considered most accurately achieved by measuring EE (per unit of time) during activity and EE is commonly measured with doubly-labeled water (DLW) or calorimetry. Therefore DLW and calorimetry have often been used as the criterion measure or primary measure for PA in the literature of PA assessment. Direct observation (DO) has also often been considered as a criterion measure. Although DO does not measure EE directly, it has been validated with EE and demonstrated to be capable of measuring PA across a broad range of settings with different age groups of people and is capable also of comprehensively describing PA. Because each of the measurement methods has different advantages/disadvantages and there is no ‘one tool fits all’, it is important to
understand the utility of each measurement tool in order to decide the most suitable method for measuring PA in the target population. This section provides an update on the validity and reliability studies of the measurement methods, a brief discussion on their specific advantages and disadvantages, as well as an update and existing studies measuring PA prevalence using each of the methods.

2.5.2.1 Criterion measure

A criterion measure in the literature of PA assessment generally refers to a measure of PA that is considered to be sufficiently representative of the actual amount of PA performed\textsuperscript{[205]}. The three measurement techniques commonly regarded as criteria for PA are: DO, DLW and calorimetry. DO is discussed in detail in a subsequent section. For the purpose of this current review, DLW and calorimetry are considered together as measures of EE. These two methods utilise different techniques to measure the same construct and are largely similar in many other aspects, such as both having excellent objectivity, very good validity\textsuperscript{[206-207]} and high costs. However, the two methods differ on how study participants may react to them, (e.g. an indirect calorimeter in the form of a back pack may cause interference to a participant while performing PA, whereas DLW is less likely to cause such an interference). The two measures of EE are both based on the thermodynamic theory that describes the relationship between EE, CO\textsubscript{2} production and O\textsubscript{2} consumption (VO\textsubscript{2}). DLW utilises

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{validation_ladder.png}
\caption{Validation ladder of physical activity measurement methods. N.B. Arrows indicate acceptable criterion standards for the validation of secondary and subjective measurement methods. Modified from: Sirard and Pate\textsuperscript{[205]}.}
\end{figure}
the kinetics of two stable isotopes of water, $^2$H$_2$O (deuterium labeled water) and H$_2^{18}$O (oxygen-18 labeled water) to predict CO$_2$ production and EE. $^2$H$_2$O is lost together with body water while H$_2^{18}$O is lost as water and as C$^{18}$O$_2$ from respiration. Therefore the difference in rates of elimination between the two isotopes equates rate of CO$_2$ production. On the other hand, indirect calorimetry measures CO$_2$ production and oxygen consumption directly through either a portable system or respiration chamber system that collect respiratory gases. The name of the technique comes from its indirect nature in calculating heat (calorie) production, which is a result of EE.

The two measures of EE have been commonly used in studies to validate other measures of PA, and in calibration studies which categorise measurement output according to EE derived PA intensity levels e.g. accelerometer cut-off derived to estimate duration of participation in activities of different intensity levels. However, both DLW and calorimetry have not been used to estimate whole day PA level, partly due to their high cost to administer. The studies in which EE was used to validate other measurement methods of PA are discussed in detail in subsequent sections.

2.5.2.2 Physical Activity Prevalence Literature Review
In a recent consortium commissioned by the Australian Department of Health and Ageing, Okely et al. \cite{154} reviewed 34 studies that described PA prevalence among children younger than six years of age. This review selected articles up to and inclusive of February 2008. Inclusion criteria for the review were: participants included children aged 5 years or younger, a minimum of 30 children and PA estimates were from whole day measurement during awake time. In addition, 3 articles published prior to February 2008 that were considered to have met the inclusion criteria were added to the database of current study. In an attempt to bridge the time lapse since the study by Okely et al.\cite{154}, further literature searches were carried out during September 2009. Literature searches were conducted in PubMed for English language articles published within the last two years, using the term ‘physical activity’ with limits of ‘Humans’, ‘Infant’ and ‘preschool child 2-5 years of age’. Articles appeared in the ‘related articles’ link in PubMed were included to maximise coverage of relevant resources. At this stage a total of 698 articles were identified. Thereafter the title was assessed either singly or in conjunction with the abstract to identify the studies which specifically investigated PA prevalence in the study sample. The inclusion criteria described by Okely et al.\cite{154} were followed. As a result, 9 articles were selected and information from these studies was extracted and tabulated (Appendix A). This literature search targeted primary research articles and systematic reviews published up to and including September 2009.
Overall the 45 studies were reviewed. The sample size ranges were 32-802 and 142-10,080 for studies using objective and subjective measuring tools respectively. Most studies reported PA levels of 3-5 year olds, only 4 included children younger than 3 years of age. Studies that estimated the level of PA in preschoolers varied widely in the methods of measurement, length of measurement period, interpretation of movement counts in the case of accelerometer measurement and PA reporting format for example some studies reported counts per minute only, whereas some described percentage of time spent in the different PA levels during measurement period. Measurement methods included accelerometers (26), pedometers (4), heart rate monitoring (1), direct observation (3) and subjective measures such as proxy-report (12).

2.5.2.3 Subjective Methods
Subjective techniques for measurement of PA generally utilise one of the following four methods: self-report questionnaires, interviewer-administered questionnaires, proxy-report questionnaires and diaries. For use with young children, self-report, interview-administered report and activity diaries have been shown to be impractical as a child may be less able to recall their PA than an adolescent or adult\(^{208-210}\). Furthermore, activity patterns in preschool children are more variable and difficult to remember, and differences in children’s linguistic ability to report their activity may also play a role\(^{211-212}\). Therefore proxy reports from parents or teachers are the only type of subjective instruments that have been used to measure PA or SB in preschool children. In general proxy-reports require adult respondents to answer the activity type, the respective frequency and duration of activity that their children partook in the recent past (e.g. 1-7 days). Often activities considered to reflect habitual SB and MVPA were specifically queried, such as watching TV, reading, art, walking, exercising and other organised activities. Alternatively, adult respondents may be asked to rate children’s usual or habitual activity. Validity of proxy-report in estimating PA levels in preschool children has been evaluated by a few studies comparing with other primary-level methods such as DLW and secondary-level methods such as accelerometry. Correlations with accelerometers have generally been moderate. For example, when compared against 3 day measurement by accelerometers, Burdette \textit{et al}\(^{213}\) found that correlations with parent reported outdoor time based on a two question checklist taken every 15-60 minutes was $r=0.33$, and with parent reported habitual outdoor time was $r=0.20$. In the study by Janz \textit{et al}\(^{214}\), a moderate correlation ($r=0.33$) was found between parental reported usual activity patterns and Actigraph counts. In infants/toddlers of 4-17 months old, Tulve \textit{et al}\(^{215}\) observed a significant moderate correlation ($r=0.42$) between Actical counts mounted
on either the hip or ankle and 4-day diaries completed by teachers. Validation studies with primary measures showed more variable findings, ranging from having no significant relationships between reported daily hours spent on activity, sleep, TV watching and EE derived from DLW among the 101 children studied\[216\], to a significantly different EE determined by Caloriecounter between the children reported by parents as ‘very active’ and ‘inactive’\[217\].

Among the 45 studies identified, 12 studies used parental proxy-report to estimate PA level in preschool children. Items enquired about in the proxy-reports were very variable with some reporting time spent outdoors, some reporting specific outdoor activities that lasted more than 20 minutes and resulted in heavy breathing, some reporting the duration that children engaged in some specified PA representing active play, and some assessing frequency of PA that reached 7 times or more a week. Comparisons across studies of PA level estimates therefore were confined to studies with comparable PA measures. Some studies reported the percentage of participation in PA among their study samples. For example, Kuepper-Nybelen et al\[218\] found that 92% of the 1,974 preschool children played outside more than once a week, while Stolley et al\[219\] found that 97.3% of the 778 African-American and 80.5% of Latino children in US exercised at least once in the last week. In another study by Ball et al\[220\], the frequency of engagement in activities considered to be moderate or vigorous was reported to be 35.2 and 36.9 times per week for boys and girls respectively. However participation of PA alone without specifying the duration and intensity makes it difficult to determine whether the overall PA level is adequate. It is more comprehensible when PA activity was reported in context. For example, Spence et al\[221\] based on parental proxy-reported hours per week of structured PA and play over two weeks period, reported a high proportion of their study sample of 501 Canadian children (85% of boys, 77% of girls) meeting the Canadian PA recommendation of 10.5 hours per week\[166\]. In another study by Okely et al\[222\], the percentage of the 266 Australian preschool children that met the NASPE Active Start Guidelines\[173\] (at least 3 hours per day of active play), was 58.3% and 52.9% for boys and girls respectively on weekdays; on weekend days the proportions were significantly higher at 76.3% and 81.8% for boys and girls. Studies that reported mean duration of PA showed a wide range of estimates. Vandewater et al\[223\] found that children generally spent 66-96 minutes per day playing outdoor depending on age (with 0-2 year olds lower than 3-6 year olds), while in another three studies estimates in outdoor play in 3-5 year olds ranged from 46.0-188.1 minutes per day\[213, 224-225\]. The estimated average duration of active play also differed between studies across a wide range. For example, Okely et al\[222\] found using proxy-report the duration of
active play ranged from 192-246 minutes per day with weekend days having higher levels. Other estimates of active play using common activities considered to represent MVPA, were 122 and 204 minutes per day for preschool children and infants respectively[226]. This decline in level with age was also observed by Taylor et al[20] with 3 year olds having the highest daily active time (81 minutes per day), followed by 4 year olds (72 minutes per day), and 5 year olds (57 minutes per day).

Subjective methods to estimate PA level, namely parent or teacher proxy-report have the advantage of ease of administration and significantly lower cost compared to objective methods which allows for application in large-scale studies. As reflected by studies discussed in the current thesis, the sample size for studies using subjective methods reached as high as 10,080 children. However, there are some inherent disadvantages to proxy-report. The characteristics and perceptions of the proxy respondent as well as their interpretations of questionnaires may introduce bias[227-228]. It has been documented in certain lifestyle modification intervention studies that children (or their families) tended to over report the level of their children’s PA and under report the level of their children’s SB[229]. Finally, a marked discrepancy has also been shown to exist in observational studies of PA in children between subjectively and objectively measured results. For example, in the Scottish Health Survey 2003[230], >75% of 6-10 year olds were reported to exceed an accumulated 60 minutes of MVPA per day every day, but other studies conducted in Scotland that have measured MVPA by accelerometers suggested that <5% of children and adolescents meet the target of 60 minutes of MVPA[10, 231-232].

In summary, studies using proxy-report to measure PA level varied widely in the aspects of PA reported. In order to obtain comprehensible estimates of PA, its duration, frequency and intensity level should be assessed in the proxy-report. Studies which report the percentage of samples meeting the recommended level by guidelines could provide information for public health purposes. Although there have been studies reporting high percentages of compliance with selected guidelines, evidence exists to indicate that this may not be replicable with objective measurement methods. Furthermore, subjectively derived levels of active play differed between studies across a wide range, signifying the main disadvantage of proxy-report: lower accuracy and consistency. On balance, there is some evidence supporting a moderate predictive power of proxy-report to estimate PA in preschool children. However the number of validation studies in this area is small and correlations with criterion measures using EE has been variable. Furthermore there is virtually no evidence on the reliability of proxy-reports in preschool children. However, proxy-report is much more feasible
than any other method for use in estimating PA levels at population level and this feature warrants continuous research to refine their use. In keeping with these findings it was recommended as a priority during a symposium sponsored by the Centers for Disease Control and Prevention, that further validity and reliability studies on proxy report are required[233].

2.5.2.4 Direct Observation

Children’s activity levels have been assessed via DO in a variety of settings. There are several published DO systems used with preschool children, each having different protocols. However in general, the protocols involve observing a child at home or in a preschool setting for a period of time and designate the child’s activity into different intensity levels. Activities are observed either continuously or on a momentary time-sampling basis for a certain time interval (ranging from 5 seconds to 1 minute). Furthermore some DO systems even describe contextual information including activity type, location and the environment in which it was performed. For example the Behaviours of Eating and Activity for Child Health: Evaluation System (BEACHES)[234], or the Observational System for Recording Physical Activity in children-preschool version (OSRAC-P)[235] both require reporting on activity type. In real time DO devices such as PDA, laptop computer or coding forms have been used for convenient annotations of PA.

In another literature review conducted by Sirard and Pate[205], eight DO systems have been identified for use with children. All of these DO systems have been validated against other measures indicative of PA levels, such as accelerometers[236], HR monitors[234, 237-240] and VO2[238]. The age of the study samples from these validation studies ranged from 2-10 years, however most studies had children aged 5 years or older. The reporting format of validities has been variable with some studies reporting correlation coefficients with accelerometer of \(r=0.72-0.90\) [236, 239] or with HR of monitor \(r=0.61-0.72\) [237], while some other studies reported findings of significantly different HR and VO2 among the observed PA intensity levels. Together, these studies provided some evidence supporting the convergent validities of DO systems, which is the extent to which an instrument’s output is associated with that of other instruments intended to measure the same exposure of interest[241]. On the other hand, DO has been used as criterion measure of PA by numerous validation studies of motion sensors. The findings from these studies were discussed in later sections ‘Pedometers’ and ‘Accelerometers’.
Direct observation is capable of gathering information on children’s activity type patterns and is flexible for use in a variety of settings. Furthermore, some DO systems also record factors related to activity performance such as location, environmental conditions, the presence of significant others and availability of toys and equipment. Obtaining such information allows for cross-sectional examination of PA and its correlates. Direct observation systems are also relatively unobtrusive for the study of PA in children. Compared to proxy-report, DO systems do not rely on a third person e.g. parent or teacher, to accurately recall PA. Some have even considered DO to be an objective measurement method for its stringent observer training and protocol ensuring satisfactory intra- and inter-observer agreement. In a systematic review by Oliver et al.\(^{15}\), the mean percentage of inter-rater agreement ranged from 84.1-100% among simultaneous observations of the same child. DO has some limitations. The lengthy time required to train observers, the length of the observation period, and the intensive data-coding requirements mean that DO is highly labour intensive and is not feasible for large-scale studies\(^{15, 154, 205, 242}\). For most DO systems it is unclear how long the observation period is required to attain day-to-day stability. As well, reactivity with children being studied has raised concerns, although Puhl et al.\(^{238}\) found that only 16.6% of the 5-6 year old children observed in their study reacted to the observers, and strategies to lessen reactivity such as familiarisation procedures or repeat observations have been proposed. Finally, although the evidence base is solid for the utility of DO, the majority of the DO systems have not been validated for use in preschool children.

Among the studies reviewed during the current thesis based on the work by Okely et al.\(^{154}\) only 3 studies were identified that used DO to measure level of PA. Bower et al.\(^{243}\) reported the MVPA level to be 12%, after observing children’s PA at 20 preschool centres for about 4 hours over 2 days. Estimates of average MVPA from another 2 studies were much lower between 2.5-3%\(^{244-245}\). These estimates were compared with estimates by other objective measurement methods in a later section titled ‘Accelerometers’.

### 2.5.2.5 Heart Rate Monitors

Rationale for using heart rate monitoring to assess PA came from the observations that HR and oxygen uptake have a linear relationship during steady state exercise\(^{154}\). It become an attractive approach as HR monitors are simple to use, relatively inexpensive and have full day storage capacity allowing for continuous, minute-by-minute HR monitoring. There is evidence to suggest that portable HR monitors provide valid assessment of HR. The Sport Tester PE 3000 portable HR
monitor was compared with electrocardiogram approach unity during a variety of activities under laboratory-based and simulated free-living settings and the correlations were very high (r=0.94-0.99) \cite{246}. However, the agreement between difficult makes of HR monitors awaits further examination.

Several problems exist with using HR monitoring. Firstly the relationship between HR and VO2 is not as robust at the low end of the PA intensity spectrum. During sedentary or light intensity activities, an individual’s HR can be affected by factors other than body movement \cite{247}. Variables that are widely recognised to influence HR include age, body size, cardio-respiratory fitness, emotional stress and caffeine or some medications \cite{248}. There are some techniques which have been devised to overcome some of the effects on HR by factors other than PA, such as the FLEX HR method for young children \cite{249}. The FLEX HR was described as an individualised HR-VO2 calibration curve that allows for distinction between resting and AEE \cite{247}. The HR at which the linear assumption does not hold is estimated and is known as the ‘FLEX’ point. Below this point EE is assumed to be equal to rest, but above this it is estimated from the slope and intercept of the line between EE and exercise HR \cite{250}. This method has been examined in validation studies with DLW \cite{247-248, 251-252} and indirect calorimetry \cite{248-249, 253-254}. In the study by Ceesay et al \cite{254} the mean error for estimating TEE was found to be only 0.6 %. However, the majority of other studies suggested that the FLEX HR method is imprecise at an individual level. These studies have generally shown an overestimate of HR over criterion measures, ranging between 0-12.3%. It was concluded by all the studies that although not suitable for use at individual level, the FLEX HR method may be used to estimate TEE and PA patterns at the group level.

In the current review based on the work by Okely et al \cite{154} the only study using HR monitors to measure MVPA estimated it to be 7% of daily awake time. This was based on the recommendation by Simons-Morton et al \cite{255} that a HR of >140 beats per minute approximates MVPA \cite{255}. In another study this cut-off was tested in forty-nine 10-12 year old girls which indicated that a HR of 140 beats per minute corresponded to 46±8% of maximum VO2, which were at the lower end of exercise intensity \cite{256}. In the same study, a HR of 160 beats per minute corresponded to 63±9% of maximum VO2, and thus may better describe MVPA in adolescent girls than the cut-off of 140 beats per minute.

On balance it has been considered that HR monitoring is a valid means of estimating EE and PA patterns in groups of people \cite{205}, however the best method for analysing
HR data to describe PA intensity remains elusive and a HR of 140 beats per minute requires further corroboration with criterion measures of MVPA.

2.5.2.6 Pedometers

Pedometers are devices that count the number of steps taken. Through measuring ambulatory activity, one of the most common everyday PAs, pedometers objectively quantify PA and there have been studies with results supporting the convergent validities of several commercially available electronic pedometers. Correlations with other PA measurement methods were: median $r=0.86$ with accelerometers, 0.82 with time in observed activity, 0.68 with direct measures of EE, and 0.33 with self-reported PA$^{[241]}$. Furthermore, validity of pedometer measurements in preschoolers has also been documented, having the mean $r=0.69-0.83$ with reported frequency of running activities$^{[257]}$, median $r=0.64$ with directly observed PA$^{[258-260]}$ and mean $r=0.73$ with accelerometer-determined MVPA$^{[12]}$. Despite having been shown to have significant moderate to strong correlations with other PA measurement methods, the levels of agreement between pedometer measurements are not as consistent. For example, a recent study compared the agreement between four different pedometer brands demonstrated that although accuracy is generally good above a walking speed of ~3.2 km/h (Intraclass correlation coefficients [ICC] = 0.985-0.997), below this speed error becomes significant and varied between pedometer brands (inter-unit agreement: ICC $\leq 0.746$, pedometer vs. observed steps: ICC $\leq 0.720$)$^{[261]}$. Similarly wide limits of agreement were seen by Oliver et al$^{[260]}$ in preschool children when they compared pedometer measured step counts with directly observed step counts during slow walk, normal walk and run over a 29 meter distance. They observed differences which ranged between 15-44 steps. However, this study is limited by having a small sample of 13 children. It was proposed that pedometers may be better suited for general assessment of accumulated activity in preschool children than for research purposes$^{[260]}$.

From the pragmatic perspective, pedometers are low cost (US$17 to 25 per unit$^{[14]}$), easy to understand and easy to integrate into practice for monitoring daily ambulation by the public$^{[14,262-266]}$. Pedometers have been recommended for use in large-scale studies when resource limitations prevent the use of more advanced objective methods such as accelerometers or when a total volume of walking activity is the outcome of interest$^{[242]}$. When evaluating pedometer determined PA levels, there were 4 studies identified from the current database which used pedometers to measure PA. The results reported varied from accumulated step count over the study period, to mean steps per minute, and mean of total daily steps. Comparisons across the studies
were limited due to the varied reporting format, however the means of total daily steps from 3 studies were 6773 steps per day\textsuperscript{[267]}, 9980 steps per day\textsuperscript{[12]} and 11,669 and 10,118 steps per day for boys and girls respectively\textsuperscript{[268]}. In the study by Al-Hazzaa and Al-Rasheed\textsuperscript{[267]}, 22\% of their study sample of 224 children reported to have exceeded 10,000 steps per day, a well known value of steps per day considered to convey good health in adults. On the other hand, in the study by Cardon and de Bourdeaudhuij\textsuperscript{[12]}, 13,874 steps per day have been put forward as equivalent to 60 minutes of MVPA (achieved by 8\% of their sample of 122 children). The 13,874 steps per day estimate was derived from simultaneous PA measurement using accelerometers which identified the minutes of MVPA.

A recommendations has been put forward for daily total step count\textsuperscript{[269]} . The value of 10,000 steps per day has become a common value considered to be representative of an active lifestyle\textsuperscript{[269-270]}, partly due to the promotion in Japan by pedometer companies and its adoption by walking clubs. Studies have shown that individuals who accumulate at least this amount of activity have less body fat\textsuperscript{[271-273]} and lower blood pressure\textsuperscript{[271-272]} than individuals with less amount of activity. For example, in a study by Moreau \textit{et al}\textsuperscript{[272]} it was found that hypertensive women who increased to 9,700 steps/day have reduced their systolic blood pressure (by 11mm Hg) and body mass (by 1.3kg) after 24 weeks of walking. There are also some concerns regarding adopting 10,000 as a universal step goal. Many people view 10,000 steps a day as not achievable by many who are aged, sedentary, or who have chronic diseases and its application to the paediatric populations has less evidence base. In fact, evidence exists to demonstrate that 10,000 steps a day is too low for children. Rowlands \textit{et al}\textsuperscript{[274]} have shown that UK children (aged 8-10 years) already take 12,000-16,000 steps a day and Vincent and Pangrazi\textsuperscript{[275]} have reported that US children (aged 6-12 years) typically take 11,000-13,000 steps a day. Fewer studies have investigated the habitual daily steps in preschool children. However, in the 4 studies reviewed, mean daily steps in preschool children ranged between 6773-11,182 steps.

In view of the persisting obesity epidemic, it is likely that 10,000 steps per day as a goal is too low for children and evidence is emerging to support a youth-specific daily step goal. There have been studies investigating the number of steps associated with desirable adiposity-related targets over the more recent years. In particular, Tudor-Locke \textit{et al}\textsuperscript{[276]} , compared the average steps per day in 1,954 children (aged 6-12 years) and related step counts to international BMI cut points for normal weight and overweight/obesity\textsuperscript{[277]} . Daily step count targets of >15,000 (boys) and >12,000 (girls) were proposed as the optimal cut-offs for predicting normal BMI (probability
of correct decisions=0.25-0.75). The study by Tudor-Locke et al\cite{276} was one of the first studies that proposed step count cut-offs for children. Subsequently, a study conducted by Duncan et al\cite{278} investigated the association of step counts with percentage of body fat (%BF). This study compared the average daily step counts in 969 New Zealand children (aged 5-12 years) with varying weight status. Significantly different average step counts was observed between non-overweight (%BF <85th percentile) and overweight children (%BF >85th percentile) and optimal step count cut-off points were 16,000 steps/day for boys and 13,000 steps/day for girls (probability of correct decisions=0.62-0.65)\cite{278}. It is apparent that the results from these two studies confirmed that daily step count guidelines for children should be set higher than those for adults, which is in keeping with recent advances in our understanding of PA needs in youth. The proposed cut-points at this time will require further cross-validation and long-term effects assessed by longitudinal studies.

2.5.2.7 Accelerometers
Accelerometers are small, lightweight electronic motion sensors that measure accelerations produced during bodily movement and convert the information into a digital signal. Most accelerometers use a horizontal cantilever beam attached to a weight on the end that compresses a piezoelectric crystal when movement is detected. Each movement generates a voltage proportional to the acceleration. Accelerometers can store data typically for 5-14 days, with some up to 356 days. In contrast to pedometers, accelerometers can provide time-stamped information on frequency, duration and levels of PA. Prevalence on SB and MVPA could therefore be directly estimated by these devices. Such an advantage come with significantly higher cost than pedometers, with one unit ranging between US$300- 4,700\cite{14}.

In order to categorise accelerometer output into sedentary, light, moderate, and vigorous intensity activities, numerous studies have developed cut-offs specific for each intensity. Alternatively, prediction equations to convert counts to units of EE have also been proposed, which could then be converted to MET to categorise PA using the definition described by the American College of Sports Medicine. Furthermore as part of the steps to assess the utility of this technological innovation, numerous studies have assessed its validity and reliability. In the aforementioned systematic review by Oliver et al\cite{15} 18 studies that assessed the validities of 5 accelerometers in preschool children were identified and compared. These studies generally analysed the correlations between accelerometer outputs with criterion measures. The 5 accelerometers validated by the studies were the Actigraph, Caltrac, Actiwatch, Actical and the Large Scale Integrated PA monitor (Table 5). In particular,
the Actigraph, Actiwatch and Actical are the three most commonly used accelerometers in the literature. These motion sensors differ in size, weight, cost and the number of planes sensitive for measurement. The Actigraph is currently the only uniaxial accelerometer that is commercially available and is the most widely used motion sensor in PA studies. It measures acceleration in the vertical plane. The Actiwatch and Actical are omnidirectional accelerometers. These accelerometers are most sensitive to movements in vertical plane but are also sensitive to other directions. The outputs are composites of the different signals. There are other accelerometry-based sensors available, however studies using these other accelerometers have generally not measured absolute levels of PA but association of PA to other variables such as maternal leisure time\cite{279}, and resting time\cite{280}. Some studies using these accelerometers were not included in this review due to the small sample size or due to levels of PA not being readily interpretable.

Validity of accelerometers in measuring PA in children

The only study reporting the validity of the Large-Scale Integrated Sensor found a low correlation with DO (r=0.38)\cite{281}. The validity of the Caltrac accelerometer was reported in 5 studies\cite{281-285}, all of which used DO as the criterion. Correlations with DO were variable across the studies (r=0.25-0.95) and one study reported no association between the two measurement methods\cite{283}. The validity of the Actigraph in preschoolers has been examined in 6 studies by using DO\cite{13,286-288}, DLW\cite{289} and indirect calorimetry\cite{290} as criterion measures. Reports on the validity of the Actigraph varied widely. Correlations between Actigraph counts and observed activity were moderate to high (r=0.52-0.87). Similarly, correlations with VO2 have been found to be high across all activities (rest, slow walk, fast walk and jog) in a laboratory setting (r=0.82)\cite{16,201}. In this same study of 30 preschool children further validity tests in an unstructured setting were conducted, in which, a moderate correlation (ICC=0.57) was observed. On the other hand, correlation between accelerometry counts and EE derived from DLW were low (r = 0.22-0.33, depending on the level of PA)\cite{289}. In a recent study assessing the agreement between EE derived from DLW and the Actigraph (based on the equations by Ekelund \textit{et al}\cite{292} and Puyau \textit{et al}\cite{293}), the limits of agreement were found to be wide and it was concluded that Actigraph appeared yet to be inadequate in estimating free-living EE in young children\cite{294}. Four studies investigated the validity of the Actiwatch. These studies once again showed mixed results. In a field study among twenty-nine 4-6 year old children, the Actiwatch activity counts were poorly correlated (r=0.27) with total EE assessed by DLW\cite{295}. Correlation with directly observed PA in seventy-eight 3-4 year old children was also poor (r=0.16-0.27, non-significant)\cite{287}. In this same study, correlation with the
Actigraph was also found to be low ($r=36$), albeit slightly better than with DO. The relationship between PA determined by the Actiwatch and DO in 40 preschoolers at their childcare centres, had a median of $r=0.74^{[296]}$. However, the range of correlation was wide, having $r=0.03-0.92$ for measurement using a 1-minute epoch$^{[296]}$ and $0.33-0.79$ for data using 15-second epochs$^{[297]}$. Finally the validity of the Actical has been investigated in two studies. Pfeiffer et al$^{[16]}$ found a high correlation between the Actical counts and VO$_2$ ($r=0.89$) under laboratory settings in 18 preschool children, while a moderate correlation (ICC=0.59) was seen with the same children under unstructured play at the preschool centres. Similar conclusions can be drawn from the study of McIver et al$^{[291]}$, during which a high correlation ($r=0.86$) between the Actical counts and VO$_2$ was observed in a group of 30 preschool children under laboratory settings. At this stage, the Actical has shown strong correlations with VO$_2$ in both laboratory and preschool settings where unstructured play was studied. However its utility is not yet certain as the evidence base on the Actical accelerometer is small and more studies are required to gain a fuller picture on its application.
Table 5. General characteristics of the five accelerometers.
Modified from: De Vries et al.¹⁴

<table>
<thead>
<tr>
<th>Accelerometer</th>
<th>Manufacturer</th>
<th>Website</th>
<th>Type</th>
<th>Data Storage (days)</th>
<th>Size (cm)</th>
<th>Weight (g)</th>
<th>Cost (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actigraph (Previously CSA and MTI. Current model is GT1M)</td>
<td>Actigraph LLC, Pensacola, FL, USA</td>
<td><a href="http://www.theactigraph.com">www.theactigraph.com</a></td>
<td>Uniaxial</td>
<td>356</td>
<td>38×37×18 mm</td>
<td>27</td>
<td>699</td>
</tr>
<tr>
<td>Caltrae</td>
<td>—</td>
<td>—</td>
<td>Uniaxial</td>
<td>No</td>
<td>70×70×20 mm</td>
<td>78</td>
<td>70-100</td>
</tr>
<tr>
<td>Large-Scale Integrated Sensor</td>
<td>—</td>
<td>—</td>
<td>Uniaxial</td>
<td>No</td>
<td>38×45×22 mm</td>
<td>51</td>
<td>—</td>
</tr>
<tr>
<td>Actical</td>
<td>Mini-Mitter, Bend, OR, USA</td>
<td><a href="http://www.minimitter.com">www.minimitter.com</a></td>
<td>Omni-axial</td>
<td>45</td>
<td>28×27×10 mm</td>
<td>17</td>
<td>1683</td>
</tr>
<tr>
<td>Actiwatch</td>
<td>Mini-Mitter, Bend, OR, USA</td>
<td><a href="http://www.minimitter.com">www.minimitter.com</a></td>
<td>Omni-axial</td>
<td>11</td>
<td>28×27×10 mm</td>
<td>16</td>
<td>4700</td>
</tr>
</tbody>
</table>

N.B. Other brands of accelerometer not used by studies included in the current review were not listed; ‘?’ no information available; ‘—‘ not commercially available (anymore).
Physical activity prevalence in preschool children

Among the studies using objective measurements, 26 studies reported the percentage of MVPA during daily awake time (Figure 7). Estimates of MVPA had a wide range (1.7-44.6% of daily awake hours) and showed differences between measurement methods as well as between studies using similar method. Such a marked variation, between studies conducted at around the same time, in the same country with the same measurement tools, seemed paradoxical. Although some variation between studies is expected, one of the factors that has become clear as causative of significant variation is the varying definitions of accelerometer measured MVPA. For example, the Actigraph alone has more than five different cut-offs for MVPA and estimates based on the Actigraph showed the widest variation of MVPA (1.7-44.6%). This effect can be seen in Figure 7, where estimates showed less variation between studies using the same cut-off compared to studies using different cut-offs. Furthermore, when accelerometer data is interpreted alternatively with average counts per minute (CPM) over the study period, less variation between studies were seen, even between studies with very different estimates of MVPA levels (Figure 8). The effect of different cut-offs has also been documented previously. For example, Reilly et al\textsuperscript{[229]} compared the results from analyses using three commonly used cut-offs for MVPA. The accelerometry data were obtained from 72 young children (31 boys, with a mean age of 5.8 year old, SD=0.5 years) studied over 7 days (mean duration of daily monitor=10.5 h/day: SD=1.1). The three MVPA cut-offs studied were those by: Puyau et al\textsuperscript{[298]}; Freedson et al\textsuperscript{[299]} (cut-offs from these two studies are discussed in a later section titled ‘Appraising the accelerometer cut-offs’) and Treuth et al\textsuperscript{[300]} which was derived from validation with free-living EE in seventy-four 13-14 year old girls.
Figure 7. Percentage of MVPA during daily awake time. Modified from: Okely et al. [154].
Figure 8. Average daily counts per minute. Modified from: Okely et al\(^{154}\).
The effect of the three different cut-offs on minutes per day and percentage of daily awake time in MVPA are shown in Table 6.

Table 6. Effect of three Actigraph cut-offs on sedentary behaviour and moderate to vigorous intensity physical activity in 72 children (aged 4-7 years).
Extracted from: Reilly et al\[229\].

<table>
<thead>
<tr>
<th></th>
<th>Puyau et al[298]</th>
<th>Treuth et al[300]</th>
<th>Freedson et al[299]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SB</td>
<td>448 (441-461)</td>
<td>180 (167-198)</td>
<td>N/A</td>
</tr>
<tr>
<td>MVPA</td>
<td>28 (27-33)</td>
<td>41 (33-48)</td>
<td>266 (254-281)</td>
</tr>
</tbody>
</table>

n.b. Data presented as mean minutes per day (95% confidence interval). Cut-offs per minute for SB: 800 (Puyau et al\[298\]); 650 (Treuth et al\[300\]). Cut-points per minute for MVPA: 3200 (Puyau et al); 3000 (Treuth et al\[300\]); 615 (Freedson et al\[299\]).

The existence of multiple sets of intensity related cut points significantly influences the estimates of preschool children’s MVPA level. Indeed, the lack of a standardised approach to objective monitoring in preschool children has made comparisons between studies difficult\[301\]. Until consensus on the cut-offs for accelerometer measured PA is reached, using the published cut-offs requires consideration of whether the cut-off was validated for the target population and how strong the correlation was with a criterion measure, whether it was based on treadmill data in a laboratory setting or free-living conditions, whether the cut-off is appropriate for the age group of the subjects, and whether the estimated MVPA is biologically plausible. In the next section, the calibration studies that published the numerous cut-offs will be discussed and assessed against the aforementioned criteria.

Appraising the accelerometer cut-offs
Among the studies in this review there were five different cut-offs of MVPA for the Actigraph accelerometer (Table 7). Freedson et al\[299\] proposed the first ever cut-off for the Actigraph. They used EE derived from oxygen exchange during treadmill exercise as the criterion and aimed to determine counts corresponding to METs=3 as the cut-off for MVPA. Their study sample consisted of eighty children aged 6-18 years. However for participants aged <12 years MVPA cut-off was not directly derivable from oxygen exchange data as their lowest EE was already ≥3.8 METs. Therefore for participants <12 year old the cut-off was extrapolated from participants between 12-18 year old. Compared with other cut-offs derived later, Freedson et al\[299\] had a much lower cut-off,
which would in turn predict higher levels of MVPA. As shown in Figure 7, high percentages (39.3-41.2%) of MVPA were predicted which would correspond to approximately 280-295 minutes during a 12 hour day. Intuitively, one would not expect a preschool child to spend up to 4 hours a day running around or doing activities of equivalent intensity on a regular basis. However, other researchers have considered levels of MVPA as high as found by Freedson et al\cite{299} seemed ‘implausible’ because of the continuing trends of increased fatness of children, even among non-obese children\cite{44,229}. Furthermore, a large proportion of the evidence base has estimated the percentage of daily MVPA during awake hours to be less than half the amount (<20%) estimated by studies using the cut-off by Freedson et al\cite{299}. Total EE measured using DLW\cite{10}, and MVPA level measured using DO, HR monitors and pedometers have also pointed towards low levels\cite{12,259}. Moreover, it is likely that the differing biomechanics involved between preschooler and older children, and between treadmill and non-treadmill activities have contributed to the tendency of this cut-off to overestimate MVPA levels among preschool children\cite{229}. Indeed, the accelerometry count distributions have been shown to be different by some between preschooler children and older children performing the same activity, and between treadmill exercise and other activities of comparable AEE.

**Table 7.** MPA and VPA cut-offs for the Actigraph accelerometer.
Modified from: Cliff *et al*\cite{302}.

<table>
<thead>
<tr>
<th>Actigraph</th>
<th>MPA cut-offs</th>
<th>VPA cut-offs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Freedson <em>et al</em>\cite{299}</strong></td>
<td>6 year olds=MPA: 615 counts/min, VPA: &gt;2972 counts/min.</td>
<td></td>
</tr>
<tr>
<td><strong>Sirard <em>et al</em>\cite{303}</strong></td>
<td>3 year olds=MPA: ≥615, VPA: ≥1231,</td>
<td>4 year olds=MPA: ≥812, VPA: ≥1235,</td>
</tr>
<tr>
<td></td>
<td>5 year olds=MPA: ≥891, VPA: ≥1255. All in counts/15s.</td>
<td></td>
</tr>
<tr>
<td><strong>Puyau <em>et al</em>\cite{298}</strong></td>
<td>6-16 year olds=MPA: ≥3200, VPA: ≥8200. All in counts/min.</td>
<td></td>
</tr>
<tr>
<td><strong>Pate <em>et al</em>\cite{290}</strong></td>
<td>3-5 year olds=MPA: ≥420 counts/15s, VPA: ≥842 counts/15s.</td>
<td></td>
</tr>
</tbody>
</table>
The next MVPA cut-off proposed for the Actigraph was by Sirard et al\cite{303}. Fifteen, 3-5 year old children were observed performing a number of selected structured activities of varying intensity levels based on the Children’s Activity Rating Score (CARS) DO system\cite{238} and other unstructured activities at day care centres. Their findings showed significant different accelerometer counts across the different activities and they developed a regression equation to predict MET from age and accelerometer counts. In the current literature, two studies using the equation proposed showed markedly different levels of MVPA (~13% vs. 45%). The work by Sirard et al\cite{303} was one of the first studies which used accelerometer counts to determine EE. However, this equation has not been cross-validated by subsequent research and is hence limited by the small sample size in the original calibration study.

Up until then studies had only been attempting to define moderate to high PA levels. Puyau et al\cite{298} hence carried out a calibration study that not only aimed to define MVPA but also SB. Through assessing the count distributions from doing several activities of differing intensities, the researchers derived cut-offs for sedentary, and light PA, as well as for MVPA using EE from room respiration calorimetry as the criterion. Their study sample consisted of twenty-six, 6-16 year old children. In addition to defining the cut-offs for the Actigraph accelerometer, the researchers carried out similar calibration for the Actiwatch, a newer, omnidirectional accelerometer. They found that correlations with EE or AEE was slightly higher with the Actiwatch (r=0.78 ± 0.06) than the Actigraph (r=0.66±0.08). However unlike the Actigraph, results for the Actiwatch have not been used by any other studies of PA prevalence within the scope of the current review. The 2 studies in this review which estimated levels of MVPA using the Actiwatch all used cut-offs based on their original calibrations, which are discussed in section ‘Omnidirectional accelerometers – Actiwatch and Actical’. The levels of MVPA estimated using this Actigraph cut-offs ranged from 2-3.5%, which is comparable with studies that utilised other cut-off based on preschoolers e.g. the cut-off by Sirard et al\cite{303}, and other measurement methods such as the Actical and DO. However, it is likely that these estimates contained potential bias from using a cut-off derived by older children. In the study by Puyau et al\cite{298} EE was found to be significantly related to age, which contributed to 2-3% of change in EE across the age-groups.

As an aside, at this point of time it was noted that although most of the calibration studies so far have found moderate to strong correlations with the criterion measure of PA, how well the accelerometer derived EE agrees with the criterion measure remained unknown. Eisenmann et al\cite{304} evaluated the regression equations to predict EE for the Caltrac and Actigraph using a portable gas analyser. They observed moderate to strong correlations between measured and predicted EE (r=0.66-0.82), however the equations from both
accelerometers underestimated EE. It was considered that the regression equations based on unidirectional accelerometers seem to underestimate EE for activities with a large force : displacement ratio, e.g. carrying weights or uphill walking, whereas activities with small force : displacement ratio, e.g. jumping or running, tended to be overestimated\(^{[201]}\).

Following on from their earlier work, Sirard \textit{et al}\(^{[288]}\) conducted another calibration study aiming to provide an accelerometry count cut-off for the use of the Actigraph in preschool children. There have been two previous studies in preschool children, however these have only identified cut-offs for SB\(^{[11, 13]}\). In the study by Sirard \textit{et al}\(^{[288]}\), 16 children aged 3-5 years were recruited during the calibration phase. Accelerometer measured PA was assessed against directly observed PA levels using the CARS while participants performed a number of selected activities. This study also developed age specific cut-offs, which were cross-validated at preschools with 281 preschool children \((r=0.46-0.70, p<0.001)\). Results of MVPA estimates using the cut-offs proposed by Sirard \textit{et al}\(^{[288]}\) were very similar across the studies and with other studies that used alternative methodologies.

Finally, with a view that the Actigraph has not been calibrated with a metabolic criterion measure, such as VO\(_2\), for its use in preschool children, Pate \textit{et al}\(^{[290]}\) conducted a calibration using indirect calorimetry and proposed cut points for MVPA. The measurements were performed with 30 preschool children during rest and three structured PA in a laboratory setting \((r=0.82\) across all activities). Cut-off points for MPA corresponded to VO\(_2\)=20 mL/kg/min, and for VPA corresponded to VO\(_2\)=30 mL/kg/min. These VO\(_2\) values were determined by visual inspection, which discriminated between steady state, slow walk vs. brisk walk, and brisk walk vs. jog. In addition, the cut points were cross-validated with indirect calorimetry in the same group of preschool children while they performed unstructured PA at their preschools \((\text{ICC}=0.57, \text{percentage agreement}=0.69-0.81, \text{for MPA and VPA respectively})\). Studies which applied the cut-off proposed by Pate \textit{et al}\(^{[290]}\) had higher estimates of daily MVPA levels than most other studies (Figure 7). This may be a reflection of the range of MVPA, as a few other studies using different methods had similar levels of MVPA. When average daily CPM was compared with other studies using different cut-offs, a higher level was observed\(^{[305]}\). However, the cut-off by Pate \textit{et al}\(^{[290]}\) is much lower compared to those of Puyau \textit{et al}\(^{[298]}\) and Sirard \textit{et al}\(^{[303]}\), which could partly explain the higher estimates. In addition, there are several differences in the study designs which could have contributed to the different cut-off derived such as the criterion measures used, and how MVPA was defined. Sirard \textit{et al}\(^{[288]}\) used DO as the criterion measure, during which selected activities were chosen from the CARS protocol to represent MPA. The MPA selected included fast walk on
treadmill (4.3 km/hr). Pate et al also used brisk walk on a treadmill to represent MPA, albeit at higher speed (3 mph, or ~4.8 km/hr). Interestingly, despite having set their MPA at slightly higher walking speed (hence having higher AEE), Pate et al's cut-off derived was lower than that of Sirard et al. This underestimate by the accelerometer may have resulted from the increased EE with carrying the indirect calorimeter (weight 925g) while the children walked on the treadmill. In fact, a well-recognised limitation of accelerometers is their tendency to underestimate activities that result in an increase in EE without a proportional increase in bodily movement. For example, static work or movement against external forces such as pushing or lifting objects, walking uphill and cycling. It has been proposed that carrying an indirect calorimeter could interfere with performing activities, and until this is controlled for it may be more suitable to measure EE by room respiration calorimetry. Furthermore, the statistical methods of cut-off derivation differed between the two studies. The ROC curve analysis was used by Sirard et al to identify the cut-off with the optimal sensitivity and specificity (which ranged from 86.7-94.4% and 66.7-100% respectively). On the other hand, Pate et al used regression analysis to identify a count cut-off corresponding to a VO2: 20 mL/kg/min for MVPA, which was then found to have a sensitivity of 96.6% and a specificity of 86.2%. It has been suggested that ROC curve analysis may be a more appropriate method for identifying cut-off when the criterion is DO, whereas the regression approach would be an analytic tool more suitable for use when the dependent variable is a continuous measure such as EE.

Omnidirectional accelerometers – Actiwatch and Actical
Since the study of Puyau et al which simultaneously validated the Actigraph and Actiwatch and revealed a slightly better correlation of the Actiwatch to the criterion measure, more researchers have begun to investigate omnidirectional accelerometers. The two accelerometers under investigation are the Actiwatch and Actical. Although both accelerometers are omnidirectional, validation studies seemed to suggest a more consistent performance with the Actical (r=0.86-0.89, under laboratory settings; ICC=0.59 under field-settings) compared with the Actiwatch (r=0.27-0.74). In a more recent study by Puayu et al, calibrations for the two accelerometers were simultaneously carried out with 7-18 year old children and the Actical correlated with room respiratory calorimetry slightly more strongly than the Actiwatch. The estimated levels of MVPA during daily awake hours by studies using the Actiwatch ranged between 4.8-13.1%, whereas the studies using the Actical had a range of 3.46-3.52%.
2.5.2.8 Summary

When selecting a method to measure PA, it is important to consider the specifics of each method in the context of the study purpose, for example an accurate account of PA levels at the individual level in a young child may be better measured by DO than using proxy-report. Following the format used by Okely et al.[154] to evaluate each of the measurement methods, important specifics to consider are summarised in Table 8.

Accelerometers have featured in the majority of studies measuring PA. Among the many accelerometer models available, the Actigraph has been studied most extensively. There have been multiple cut-offs derived to define MVPA using the Actigraph, however the application of these cut-offs by other studies may not be appropriate for some subgroups of the population. For example, previous studies have demonstrated population specificity in the relationship between accelerometry counts and EE[298, 306-307], and it has been observed by some studies that age and factors associated with age could influence this relationship[288, 298, 307]. Overall, for children aged between 3-5 year old the current evidence base seems to suggest the most appropriate cut-off for a MVPA when using the Actigraph, with 1-minute epochs, to be in the range 3,000-3,600 counts/min[288, 298, 300]. This cut-off would correspond to MVPA estimate of approximately 3-6% of daily awake time, a comparable estimate supported by many studies using other measurement tools such as the Actical, DO and HR monitors. The levels of MVPA were estimated by 21 studies to be approximately between 1.7-17.6% of the daily awake time in preschool children, with a larger proportion (14 of 21 studies) pointing towards the lower end (1.7-6%). Of a 12 hour day, these ranges would correspond to between 12-126 minutes spent in MVPA, or 12-43 minutes, respectively. A comprehensive understanding of PA prevalences in children is still evolving and can only be achieved through multiple studies using different measurement methods with supporting evidence on their validities, and investigating potential confounding factors within subgroups of the study population. Comparisons across studies could be more readily conducted through measuring PA with contextual information such as proportion of daily awake time.
<table>
<thead>
<tr>
<th>Method</th>
<th>Valid</th>
<th>Reliable</th>
<th>Objective</th>
<th>Non-reactive</th>
<th>Ease of admin.</th>
<th>Measures patterns, modes, and dimensions of PA</th>
<th>Affordable</th>
<th>Feasible in large studies</th>
<th>Suitable for age &lt;5 yo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proxy-report</td>
<td>X</td>
<td>P</td>
<td>P</td>
<td>XXX</td>
<td>XXX</td>
<td>XX</td>
<td>XXX</td>
<td>XXX</td>
<td>-</td>
</tr>
<tr>
<td>HR monitor</td>
<td>XX</td>
<td>XXX</td>
<td>XXX</td>
<td>X</td>
<td>X</td>
<td>XX</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Direct observation</td>
<td>XXX</td>
<td>XXX</td>
<td>XX</td>
<td>X</td>
<td>X</td>
<td>XXX</td>
<td>X</td>
<td>P</td>
<td>XXX</td>
</tr>
<tr>
<td>Pedometer</td>
<td>XXX</td>
<td>X</td>
<td>XXX</td>
<td>XX</td>
<td>XXX</td>
<td>P</td>
<td>XXX</td>
<td>XX</td>
<td>XXX</td>
</tr>
<tr>
<td>Accelerometer</td>
<td>XXX</td>
<td>XX</td>
<td>XXX</td>
<td>XX</td>
<td>XXX</td>
<td>XXX</td>
<td>X</td>
<td>X</td>
<td>XXX</td>
</tr>
</tbody>
</table>

N.B.  

P  Poor or Inappropriate  
X  Acceptable  
XX  Good  
XXX  Excellent
Several causal factors have been identified to be strong predictors for the development of overweight/obesity, which include the focus of the current study: PA. However, search for a measuring method that is valid, reliable and feasible for measuring levels of PA in population of preschool children has proven to be a challenge and every method has its own specific advantages and disadvantages. It seems that to-date, accelerometry provides the best all-round performance and work has continued to refine this technology. The newest model of omnidirectional accelerometer, the Actical, has shown some promising results over other accelerometers and a small number of studies have derived cut-offs for the Actical to identify MVPA in children. However, no formal publication exists for a cut-off of SB for preschool children. As measuring SB is potentially just as important as measuring PA, this study aims to provide a validated cut-off to define SB using the Actical accelerometer.
CHAPTER 2.6: THE ROLE OF SEDENTARY BEHAVIOURS
IN CHILD HEALTH

2.6.1 The Health Effects of Sedentary Behaviour

Sedentary behaviour is an entity that has received more and more attention in the field of overweight/obesity research. Along with the increasing understanding that PA is integral to good health, SB has become clearly associated with a number of risk factors for health problems. In the context of the overweight/obesity discussion, SB is not simply the absence of PA but involves purposeful engagement in activities that involve minimal movement and low EE\(^{[13, 308]}\).

The majority of studies investigating the association between SB and weight status in preschool children have reported a positive relationship between levels of SB and risk of being overweight\(^{[154, 309-311]}\). Intervention studies with 8-12 year old children have also supported targeting SB as an adjunct in the treatment of paediatric overweight\(^{[19]}\), with some even concluding that reducing levels of SB could be more effective in preventing excessive weight gain than targeting increases in PA\(^{[18]}\). However, results from intervention studies in preschool children are less clear, mainly due to the scarcity of intervention studies in children of this age group. The one study that compared the effect of reducing TV viewing with no intervention in preschool children found no difference in subsequently measured levels of BMI or triceps skinfold between the two groups\(^{[312]}\).

Associations of SB to various other health-related outcomes have been reported by a number of studies. In terms of cardiovascular health, a large prospective cohort study in New Zealand followed approximately 1,000 participants from the age of 5 years up to 26 year old to compare the results of parental reported time their child spent watching TV on an average weekday, and participants’ blood lipids, blood pressure, cardio-respiratory fitness and smoking status. It was found that TV viewing during childhood is significantly associated with higher total cholesterol, lower cardio-respiratory fitness and higher odds of smoking by age 26\(^{[313]}\). There was no significant association found with blood pressure. Other studies in older children and adolescents have reported equivocal findings on the association between SB and cardiovascular health\(^{[314-315]}\), however evidence reporting the association of SB with higher cardiovascular risk profiles exist in a significant larger proportion. Several studies have also investigated the possible
association SB has with young children’s development. It has been consistently shown by prospective observational studies that time spent in TV watching in children under 5 years of age was associated with poorer development of language skill, cognition, short-term memory and poorer academic achievements at follow-ups ranging between 1 to 9 years\textsuperscript{316-320}. Interestingly, when sub-categories of language skill development were assessed, expressive language growth rate was found by one study to be associated with a higher TV watching time\textsuperscript{317}. Motor development and musculoskeletal health in relation to SB in preschool children has been examined by a small number of studies. Janz \textit{et al}\textsuperscript{321} has found that a lower bone mineral density is significantly associated with time spent in TV watching by girls. No such association was seen with boys. In another study, Cliff \textit{et al}\textsuperscript{322} determined time spent in SB in a group of 46 preschool children using the Actigraph accelerometer and assessed its relationship with motor development. However, results from this study were inconclusive.

As can be seen in the majority of studies on SB, TV watching is commonly targeted in studies investigating the association between SB and health measures. Indeed the existing guidelines on SB engagement for preschool children have targeted screen time and have recommended limiting time spent on watching TV and video time to a maximum of two hours per day\textsuperscript{323-324}. This is partly due to that some parents and carers would not view other SB as harmful to their child’s health. Examples of such SBs may include sitting activities such as playing puzzles, reading or travelling in a car. There is also some evidence suggesting that levels of TV viewing might track from the preschool period\textsuperscript{325}. Furthermore, with the advancement of technology, using electronic media is becoming ever more common in everyday lives, activities such as watching DVDs, using computers or playing video games have provided more opportunities for lengthening the daily ‘screen time’. It should be borne in mind however, that screen time is a heterogeneous group of activities and the content of which could encourage children to participate in different levels of activity, such as interactive programmes that encourage the child to dance. There are also programmes which have been designed to enhance certain aspects of development in young children e.g. ‘Dora the Explorer\textsuperscript{TM}’ on language skills. Currently, little has been studied on what young children do during screen time. Research seems to suggest that children pay little attention to TV until around two and half years of age and that they interact more with live interactions than with comparable shows on TV – an effect referred to as the ‘video deficit’\textsuperscript{326}.

In conclusion, the evidence base to-date suggests that excessive TV watching could be associated with certain risk factors of child health, which includes excessive adiposity, worse cardio-respiratory risk profiles and poorer cognitive development. On the other
hand, there have been reports suggesting no association between TV watching with some indicators for health risks such as high blood pressure and poorer motor development. Although educational screen programmes may provide some benefits to certain aspects of children’s development, there is currently not enough evidence on this field to support their use and parents and carers should not substitute their interactive educational sessions through play with screen time. There are very few intervention studies available, possibly due to lacking a reliable objective measurement tool that would allow inspecting at a higher resolution, the quantitative relationship between SB and outcomes. Work is indicated to enhance the current knowledge of health-related measures associated with SB, and to clarify the causal relationship seen in the associations, with the possibility of describing dose-response effects from reducing the level of SB. More intervention studies involving preschool children are also indicated.
2.6.2 Levels of Sedentary Behaviour

There are fewer studies measuring level of SB than PA in preschool children. All the studies using accelerometry, have used the Actigraph accelerometer. The range of SB reported by these studies is wide (34%-94.5% of daily awake time). However, most studies have reported the prevalence to be between 60-80%. Assuming the duration of daily awake time to be 15 hours, the estimates of daily SB approximately corresponds to between 9-12 hours per day. A few studies used DO to estimate level of SB in preschool children. The reported estimates of observed time being sedentary varied between ~55-88%[154]. There is a larger body of evidence from studies that have used parent-proxy reports to estimate levels of SB in preschool children. Most of these studies targeted TV watching to provide information on levels of habitual SB. By far the majority of these studies with preschool children have reported between 2-3 hours per day of TV watching time[154].

There are certain limitations to the methods used to-date in estimating SB level. Similar to measurement of PA, the level of SB estimated by accelerometers used a count cut-off which varied between studies. For example, the cut-off by Janz et al[327] (<104 CPM) is a lot lower than the cut-off by Reilly et al[13] (<1100 CPM), which once again clearly influences the amount of reported SB. Secondly, it should be noted that TV watching alone may not provide an accurate estimate of the amount of habitual SB[229]. On balance, the level of SB estimated by most of the objective methods ranged from 60-80% of daily awake time, while amount of TV watching estimated by parent proxy-report appears to be as high as between 2-3 hours per day. There is a need for more studies using different measurement methods or models of accelerometer to strengthen the current evidence base on estimating levels of SB.
CHAPTER 3: METHODS

3.1 Participants

Fifty healthy children (25 boys), ten for each year of age from 3 to 7 were recruited through advertisements placed in a local preschool and a primary school, invitations to colleagues and friends with children and invitations sent by the schools to selected families within the preschool and primary schools in Dunedin, New Zealand. The families were a convenience sample selected within the conditions of age and gender to obtain an equal distribution of participants across the 3 to 7 year old age range. Exclusion criteria were: outside the normal range (the 3rd and 97th percentiles) for age-specific height, weight and BMI standards, major congenital abnormalities or severe chronic illness or inability to participate in PA. Recruitment was carried out from April to September 2009. The study protocol was approved by the University of Otago Human Ethics Committee in April 2009 (Ethics Committee reference number: 09/054). Informed written consent was obtained from the parents and if applicable, the child.

3.2 Materials and Apparatus

3.2.1 Scales and Stadiometer
A Hanson HFA 4 Body Fat Analyser Scale (Model GSHANHFA4GE-R3) was used to weigh the children individually. The scale was calibrated prior to commencing the study and monthly during the study by measuring standard weights up to 21 kg. This scale was capable of measuring up to 140 kg and readable to the nearest 100g.
A portable stadiometer was used to measure heights of children. This stadiometer was designed and built by the University of Otago for use in the 1997 New Zealand National Nutrition Survey. The stadiometer is capable of measuring up to 220 cm and readable to the nearest 0.1 cm. Prior to commencing the study the stadiometer was calibrated using Perspex calibrating stands of known height (72 cm).

3.2.2 Accelerometry
The Mini-Mitter Actical accelerometer (Bend, USA) is a small, lightweight (29 x 37 x 11 mm, 16 g) and water resistant motion sensor which records detailed information on the magnitude of acceleration during bodily movement, PA intensity, and date and time of activities. It is an omnidirectional motion sensor that is capable of capturing movement in
multiple planes (sensing motion primarily in a single plane and less sensitively in other planes). Movements ranging from 0.5- to 3-Hz are detectable by the sensor, which encompasses movements from sedentary to vigorous\textsuperscript{[16]}. The sensor functions via a cantilevered rectangular piezoelectric bimorph plate and seismic mass. This piezo-electric sensor is oriented in the Actical such that maximum sensitivity is obtained when the centre of body mass is moved against gravity, e.g. when positioned on the hip the Actical is most sensitive to vertical movements of the trunk\textsuperscript{[201]}. When movement is detected the seismic mass compresses the piezoelectric plate and a voltage is generated proportional to the acceleration. Voltage generated by the sensor is then amplified and filtered via analog circuitry and passed into an analog to digital converter. This process is repeated 32 times per second. The resulting 1 second value is divided by four, then added to an accumulated activity value for the epoch\textsuperscript{[16]}.

**Calibration**

For the current study, two accelerometers were randomly selected from a batch of 20 Actical accelerometers issued to the author and supervisors in January 2008 from the Mini Mitter Company, USA. Throughout the data collection phase, before each working session, comparisons on the two accelerometers were carried out by measuring movement generated by a custom-made calibration machine (Figure 9). The machine was capable of creating consistent, shaking movement with adjustable speed and allowed testing of up to 8 Actical accelerometers simultaneously. The accelerometers were compared for three different conditions of slow, moderate and vigorous movement for 5 minutes each. Similar comparisons were carried prior to commencing the study with 10 randomly selected Actical accelerometers to evaluate the precision of measurements.

**Actical use**

The accelerometer was secured with an elastic belt which was worn by the child on his/her hip, resting on the iliac crest. Placement on the hip has been shown to provide the most accurate measurement of movements\textsuperscript{[329]}. The accelerometers were programmed with the child’s age, gender, height and weight by using the manufacturer’s software, initialised to save data in 15 second intervals (epochs) to detect the spontaneous activities of children.
Figure 9. Photos of the custom-made motion generator.
A – Actical accelerometer mount, showing clamp and control panel
B – Show the control panel
3.2.3 Activities
There were 7 main activities performed by the children. Some of the activities were similar in nature (e.g. the sitting activities, see Table 9) whilst some differed in the amount and intensity of movements likely to be involved. Most of the activities were commonly seen among children’s everyday activities and they were purposely selected to reflect a broad range of PA intensities in a normal preschool setting. The content of the activities is described in Table 8. Five of these activities (sitting activities) were selected to represent sedentary leveled activities, which involved minimal bodily movements in a sitting or reclined position. One activity (playing with toy cars) was included to provoke movements of slightly higher intensity level than sedentary, to reflect light activity. One activity (playing Nintendo Wii Sports™ - Boxing) represented moderate/vigorous activity. In addition, when conditions permitted, the children’s free play in an outdoor playground (provided dry weather condition and availability of a playground) and lunch time naps (provided the child slept during his/her time at preschool) were also studied. Except for free play, one researcher participated with the child, with or without his/her classmates depending on the child’s choice. All of these activities were familiar to the children except for playing the Nintendo Wii which most of the preschool-aged children had little experience with before the study. With this activity, the researcher explained in simple terms what the aim of the game was and demonstrated how the game was played before commencement. Throughout the game, the researcher played the game with the child and verbal encouragement was given to maintain motivation as much as possible. Each activity was performed for between 5 and 10 minutes.

3.2.4 Video Recordings
For all activities, in addition to the accelerometer measurements the child’s activities were recorded by the Sanyo Xacti Digital Camera (Model VPC-J4EX) mounted on a tripod (Lander L800 Video/Photo Tripod). Two 512 megabit SD memory cards were used to provide about 94 minutes recording capacity. The video recordings were taken at 320 x 240 pixel resolutions at 15 frames per second. These settings were confirmed during the pilot period to be capable of providing good clarity video recordings for observational purposes. Activities carried out by the children were able to be clearly described. The observed PA served as the criterion measure against which accelerometer measurements were compared.
Table 9. Description of activities performed by the children.

<table>
<thead>
<tr>
<th>Name of activity</th>
<th>Description of activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Draw</td>
<td>A small table and 2-3 chairs of suitable sizes for children were arranged in a quiet room in the preschool/school. Colouring pens and a colouring paper of popular cartoon characters such as ‘Bob the Builder™’, ‘Winnie the Pooh™’ or ‘Dora the Explorer™’, according to the child’s preferences were provided. The child was then asked to colour in the paper at their own pace.</td>
</tr>
<tr>
<td>Play Doh</td>
<td>In a similar setting as described with ‘Draw’, a set of Play Doh with animal, number and letter plastic moulds was provided. The child played Play Doh at their own pace while seated.</td>
</tr>
<tr>
<td>Puzzle</td>
<td>A 60 piece puzzle with a ‘Winnie the Pooh’ picture was used with school-aged children while smaller puzzles suitable for preschool-aged children were used. Children played the puzzle while seated and were challenged to complete the puzzle within 10 minutes, with help from the researcher.</td>
</tr>
<tr>
<td>Read</td>
<td>One book was selected from the book shelves at the preschool/school by the child to read with a researcher. The researcher either read to the child (for those children who could not yet read) or took turns with the child to read. Techniques such as asking the child to count, name or look for a specific object were used during reading to maintain his/her interest.</td>
</tr>
<tr>
<td>TV</td>
<td>The child sat on a chair, cushion or bean bag of their choice and a DVD of a popular cartoon with 10 minute long episodes such as ‘Bob the Builder’ or ‘Winnie the Pooh’ was played on the TV.</td>
</tr>
<tr>
<td>Toy Car</td>
<td>A plastic, 70 cm × 70 cm city floor mat was put on the floor for this activity with all furniture put away. The child was provided with a plastic, 17 cm long toy car and asked to drive his/her vehicle around the city at his/her own pace.</td>
</tr>
<tr>
<td>Nintendo Wii</td>
<td>Nintendo Wii Sport™ – Boxing was played by the child. The child held the controls with both hands and was taught to ‘punch’, ‘dodge side ways’ and ‘shake arms up and down’ as the three movements to play the game. These movements were performed at different times during the game according to the game progress.</td>
</tr>
<tr>
<td>Sleep</td>
<td>Only some children at the preschool slept during their stay there. Observations were carried out in the sleep room after the child was confirmed to be asleep, determined by lying still for ≥5 minutes.</td>
</tr>
<tr>
<td>Free Play</td>
<td>The child was asked to participate in activities of his/her choice in the outdoor playground at the preschool or school.</td>
</tr>
</tbody>
</table>
3.3 Protocol

3.3.1 Locality Selection
The preschool centre and primary school were chosen on the basis of convenience. The preschool centre was within walking distance of the researcher’s office and the primary school was a convenient 5 minute drive away. The Manager or Principal of the preschool centre and school were approached in person and the project outline discussed. Locality approval forms were signed by the manager/principal.

3.3.2 Participant Recruitment
Advertisement posters were placed on notice boards in the preschool centre and school. In addition, an invitation email was sent to colleagues and friends of the researchers who had children aged between 3-7 years. The families, colleagues and friends that expressed interest about participating in the study were given an information sheet. After written consent was obtained, a questionnaire collecting information on the child’s demographic, birth history and general well-being was completed by the parents. As more participants than the number of families responded to advertisement were required, newsletters containing a brief introduction about the research and invitation letters from the principal investigator were distributed by the preschool/school to families randomly selected within conditions of their child’s gender and age.

3.3.3 Height, Weight Measurement and BMI Calculation
Height and weight measurements were part of the assessment for eligibility and for programming the Actical accelerometers. The measurements were performed without shoes and with children wearing light clothing. Children were measured standing upright on the stadiometer. Foot position was standardised by placing the child’s heels on the marked line on the base plate. Upright posture was checked by ensuring children’s legs were straight, and their heels, hips and shoulders were parallel. Head position was checked to ensure that children were looking straight with no forward or backward head inclination and the Frankfort plane was horizontal. Measurements were then made by lowering the slide bar to rest gently on top of the child’s head. Each measurement was obtained to the nearest 0.1 cm and the process was repeated until the measurements differed by less than 0.5 cm. The average of the two closest measurements was taken as the final height. The child was then asked to step on the scale until the reading stabilised. If the child moved excessively during weighing, the measurement was discarded and the process repeated. Once again repeated measurements were obtained until the difference between measurements differed by less than 0.5 kg.
The average of the two closest measurements was taken as the final weight. The child’s BMI was calculated as:

\[
\text{BMI} = \frac{\text{Weight (kg)}}{\text{Height}^2 (\text{m}^2)}
\]

BMI-for-age percentile was calculated using the Centers for Disease Control and Prevention BMI calculator\[330\].

### 3.3.4 Physical Activity Measurement

Well-lit, thermal comfort rooms were available for the researcher to use at the preschool centre and school. Regardless of the locations, the rooms were similarly arranged, containing a table and chairs of suitable height for the children, a TV set connected to a DVD player and the Nintendo Wii console. After the child arrived at the preschool/school, the accelerometer was placed on the child as described earlier. The child was then asked to partake in the activities. Throughout the entire observations the digital camera and tripod were placed at a distance to allow the child’s activity to be clearly and fully captured. This required some judgement from the researcher to balance the filmable area frame and the clarity of activity. However a suitable starting point was to have the camera/tripod placed at 45° facing the child, 2 metres away, and with the camera at a height of between 1 to 1.5 meters from the ground.

The activities were carried out either with the researcher alone or with friends, depending on the children’s choice. Each of the activities was undertaken for a period of between 5-10 minutes and the total duration of observations usually ran between 1.5-2 hours. For every child, a second session was arranged if required to finish the activity observations. During the activity, if required the child was prompted as much as tolerable to persist with each activity. Motivation was maintained by support and verbal positive reinforcement from teachers, parents and researchers and at the end of the study a certificate and some stickers were given to the participants. If the child declined to participate in a specific activity, the activity was withheld during the session and retried in a second session of a later date. However if the child refused to partake in the specific activity on both occasions, such an activity was discarded for observation. Except for play in the playground all other activities were performed indoors. The activities were performed in a way that Nintendo Wii was played after three other indoor activities which effectively provided a break amongst the other less vigorous activities. The order of activities was otherwise randomised within this format. If the child slept, it always
occurred approximately half an hour after his/her lunch. Lunch time nap sleep was observed at the childcare centre for those children who had a day time sleep. In the sleep room at the childcare centre curtains were closed and relaxing music was played to establish a comfortable atmosphere for sleep. Some teachers were always present and if the child required, encouragement to sleep was given. Once the child was asleep as determined by having remained motionless or with minimal movement for 5 minutes, observation took place. Filming in the dark was achieved by using a small torch as the source of light shone at the bed parallel to the direction of filming. This simple technique also ensured that sleep was not disrupted by the filming process.

When conditions permitted (i.e. a playground was available, outdoor play was allowed by teachers and weather was fine for outdoor play) the child’s free play activities in an outdoor playground were also studied. Once in the playground the child often engaged quickly with an activity chosen at his/her will, either with friends or alone. Filming technique during outdoor activity differed to some extent to indoor activities. However the aim was again to achieve a desired balance of filmable frame area and clarity of activity.

Collection of data was mostly carried out at the preschool centre or school. For participants recruited outside the preschool centre/school (6 participants), data collection took place in the research room in the Children’s Pavilion, Dunedin Public Hospital. Throughout the study, the two accelerometers were reset at the beginning and read at the end of each data collection session. Time-stamped data from the two accelerometers were downloaded and exported to Excel™ (Microsoft Corp., Washington, USA) when data collection was finished.

3.3.5 Synchronisation and Data Coding
The digital camera was synchronised daily with the computer used to initialise the accelerometers so that observation and Actical data could be temporally matched. The digital camera recorded the start times of each observed activity in seconds. These times were then used to extract the corresponding activity monitor data. After the video recordings and the Actical data were synchronised, each individual video recording was reviewed by the researchers and activity was annotated for 15-second epochs in accordance with the 15-second epoch measurement by the Actical. A simple binomial system was utilised and activity was coded as either ‘confirmed’ or ‘unconfirmed’. Observation was annotated as ‘confirmed’ when the child was engaged in the activity during the 15 second clip, whereas ‘unconfirmed’ was annotated when the child for any duration was no longer participating in the activity AND switched his/her attention
entirely to a different activity. For free play only, unconfirmed was annotated when there was interaction with the observer.

3.3.6 Statistical Analysis
Activity counts were extracted and imported into Excel which were subsequently analysed as outlined below using STATA 9.0 (StataCorp LP, College Station, TX). $\alpha = 0.05$ was set for determining statistical significance.

Reliability test
The measurements taken when the two accelerometers measured movements generated by the motion generator were used to calculate the average Actical counts for all 5 minutes of each activity speed. Intra-instrument and inter-instrument reliabilities for the two monitors were evaluated by calculating the Pearson product-moment correlation coefficient ($r_p$), while intra- and inter-instrument agreements were assessed by drawing Bland-Altman plots. One set of measurements obtained using the motion generator from the beginning, middle and end stage of data collection was randomly selected for analysis of instrument performance.

Activity counts and cut-off derivation
Means and standard deviations were calculated for Actical 15 second count values for each of the activities. A zero-inflated negative binomial regression model was used to detect differences in count distributions between the activities.

Receiver operating characteristic (ROC) curves were plotted to identify the sedentary cut-off count value. The technique of ROC curve analysis has long been used in a variety of situations for selecting classifiers based on their performance, such as in medicine to evaluate the performance of diagnostic tests\[331\]. In the setting of PA measurement by accelerometers, using a given quantitative cut-off to identify a specific PA intensity level and comparing the result with a criterion measure, a certain proportion of counts will be true positives (PA level correctly identified by the accelerometers), true negatives (non-PA level correctly identified), false positives (non-PA level incorrectly classified as PA level), and false negatives (PA level incorrectly classified as non-PA level). Sensitivity and specificity can also be determined and a ROC curve is plotted with sensitivity along the y-axis and 1-specificity on the x-axis. Using the ROC curve the performance of the cut-offs (indicated by their respective sensitivity and specificity) can be visualised and the cut-off with the maximal overall performance selected.
Accelerometry counts confirmed to be corresponding to the 5 sitting SBs from all age groups were pooled together to plot the ROC curve. Sleep was not included in the ROC curve analysis due to having significant different mean counts and dispersion. Sensitivity and specificities were calculated based on how the cut-offs discriminated between confirmed SB and confirmed non-SB (Toy car, Nintendo, Free Play).

**Validity test and cross-validation**

In order to assess the convergent validity of the Actical accelerometry, accelerometer counts were compared with the results from video coding using the Children’s Activity Rating Scale (CARS)\[^238^\]. The CARS is a protocol-based DO technique that has been widely used as a criterion measure of PA in validation studies of other PA measuring tools\[^205^\]. The CARS has previously been shown to be capable of discriminating between levels of EE in 5-6 year old children and the mean inter-rater reliability in the same study with a different group of preschool children has been high\[^238^\]. Using the CARS entails annotating 1 of the 5 levels of PA described by the protocol for each epoch of observation. The original study set epochs of observation at 1 minute. However a 15-second CARS epoch has been tested in a group of preschool children\[^288^\] and supports the adaptability of CARS to differing epoch lengths.

During the study, the researcher and one research assistant completed 5 hours of training on administering the CARS. Video clips of children’s free play obtained in the study were simultaneously annotated by the researcher and research assistant, on a second by second basis. Each annotation was reviewed and any differences discussed until agreement was reached during the 5 hour training period. Any uncertainties left from the initial training period were discussed with a senior research colleague who is experienced in using the CARS to clarify appropriate coding methodology. For the validity testing, free play video clips from the group of 5 year old children were used. Two extracts of 2 minute duration were randomly selected from the free play video clips. The extracted clips were not necessarily consecutive. Activity level was annotated for a second-by-second epoch and the CARS scores were averaged over 15-second epochs corresponding to the accelerometer measurement epochs. Convergent validity was determined by calculating the Pearson product-moment correlation coefficient between the CARS scores and accelerometer counts.

In order to test the established accelerometer cut-off in free-living situations, the video clips coded by the CARS were extracted and the proportion of time the child engaged in SB was estimated using the cut-off derived. Accelerometer counts above the cut-off were defined as non-SB. Criterion for SB was provided by DO using the CARS score and was
defined as having a score between 1 and 2, whereas non-SB was defined as greater than or equal to 2. The differences of SB estimates by the two methods were calculated (CARS–Actical) for each of the nine 5 year old children. Statistical mean of differences, and a standard deviation were calculated and a paired $t$ test was performed to compare the two sets of estimates.
CHAPTER 4: RESULTS

4.1 Recruitment and Demographic Information

Fifty healthy children were recruited to the study. Of this study population 10 children were recruited through advertisement, 7 children by invitation to colleagues and friends with children and 33 by invitation sent by the preschool/school. With the latter, 36 families were invited to participate, therefore the study had a recruitment rate of 92%. One male participant from the 7 year old group was not included in the study due to illness during the period for data collection. Thus, the final number of participants was 49. The overall health of these children was described by parents as ‘Excellent’ (28), ‘Very good’ (19) and ‘Good’ (2). The baseline characteristics of the study population are summarised in Table 10.

<table>
<thead>
<tr>
<th>Table 10. Baseline Characteristics of Study Population.</th>
</tr>
</thead>
<tbody>
<tr>
<td>3yo</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>N</td>
</tr>
<tr>
<td>Gender (M:F)</td>
</tr>
<tr>
<td>Ethnicity (N=European)</td>
</tr>
<tr>
<td>Height (cm)</td>
</tr>
<tr>
<td>Weight (kg)</td>
</tr>
<tr>
<td>BMI (kg.m⁻²)</td>
</tr>
<tr>
<td>BMI for age percentile</td>
</tr>
</tbody>
</table>

N.B. Data presented as mean (standard deviation) except where specified.

Height, weight and BMI distributions were comparable with previously published data on New Zealand children[20,332]. Overall, the sex distribution was even, as per the recruitment protocol. Participants were mostly European. Two children were described by parents as Maori, 1 child as Samoan and 1 child as Chinese.
4.2 Reliabilities of the Actical Accelerometers

Comparisons between accelerometer counts using the motion generator showed that both intra-instrument and inter-instrument reliabilities were high throughout the study ($r_{p\text{-intra}}$ and $r_{p\text{-inter}} = 1.0$). However when intra-instrument agreement between repeated measurement was assessed by Bland-Altman plots for the two accelerometers using data from the beginning, the mid-point and the end of the data collection phase, count differences existed. The differences however were small, within 10% at low speed, and 5% at both moderate and high speeds as exemplified by Figure 10 (taken from the mid-point of the data collection phase). Such percentages of differences were considered to indicate good ($<10\%$ of average count) and very good ($<5\%$ of average count) agreement. Inter-instrument agreement evaluated using a similar method for data extraction revealed that one accelerometer tended to measure with higher counts over the other accelerometer as exemplified by Figure 11 (taken from the mid-point of the data collection phase). At low speed (average count $<500$), the differences were greatest (34-50% of average count) compared with at mid speed (average count 500-1,500) where differences were less than 15% and high speed (average count $>1,500$) where differences were less than 10%. 
Figure 10. Intra-instrumental reliability (Actical I, time 1 vs. Actical I, time 2). N.B. dashed lines represent 5% increment values of the average counts.

Figure 11. Inter-instrumental reliability (Actical I vs. Actical II). N.B. dashed lines represent 5% increment values of the average counts.
4.3 Performing the Activities

The activities were largely well accepted by the participants and took between 1.5-2 hours in total to finish. Some children, particularly those aged 3-5 years, did not complete all activities in one session as PA monitoring had to pause at times when they were due to participate in other routine activities in the preschool centre e.g. morning tea/lunch, birthday celebrations or play in the park. For these children a second session was arranged to complete the PA monitoring. Three hundred and eighty three observations were made for an average time of 8.8 minutes, giving a total observation period of approximately 3370 minutes. Overall, for only 2.4% of the observation times were the children ‘off task’. Table 11 outlines the frequency and duration for both confirmed and unconfirmed observations for each activity.

Table 11. Frequency and duration for confirmed and unconfirmed observations of the activities.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Draw</th>
<th>Play</th>
<th>Puzzle</th>
<th>Read</th>
<th>Toy Car</th>
<th>TV</th>
<th>Sleep</th>
<th>Nintendo Wii</th>
<th>Free Play</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freq. of obs.</td>
<td>49</td>
<td>49</td>
<td>46</td>
<td>49</td>
<td>49</td>
<td>49</td>
<td>8</td>
<td>45</td>
<td>39</td>
<td>383</td>
</tr>
<tr>
<td>Freq. of missed obs.</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Duration of each obs. in mins. mean (SD)</td>
<td>9.3 (0.9)</td>
<td>9.4 (1.3)</td>
<td>9.2 (1.4)</td>
<td>9.5 (0.8)</td>
<td>8.7 (1.9)</td>
<td>9.2 (1.4)</td>
<td>9.7 (0.5)</td>
<td>5.9 (2.2)</td>
<td>9.3 (1.4)</td>
<td>8.8 (1.8)</td>
</tr>
<tr>
<td>Unconfirmed obs. (%)</td>
<td>1.5</td>
<td>1.5</td>
<td>1.3</td>
<td>3.6</td>
<td>2.8</td>
<td>5.6</td>
<td>0.0</td>
<td>2.4</td>
<td>1.2</td>
<td>2.4</td>
</tr>
</tbody>
</table>

Freq., frequency of observation for the activity; obs., observation; observation was annotated as unconfirmed for the 15s epoch when the child was no longer participating in the activity during the period of observation AND switched his/her attention entirely to a different activity; for free play only, unconfirmed was annotated when there was reactivity with the observer.

Total number of observations were 49 for each of the activities except for sleep and free play, as only a few younger children slept during the time at the preschool centre and the playground facility for free play was not available for all children. The missed observations were due to different reasons for the different activities. ‘Nintendo Wii’ was missed due to the children’s decisions to withdraw from the activity, whilst adverse
weather conditions accounted for the missed ‘Free Play’. The missed observations for ‘Puzzle’ was due to 3 children deciding to play puzzles on the floor instead of on the table in sitting position. Positioning was considered to be influential to the types of PA involved during the activity hence these 3 observations were removed.

4.4 Description of counts for each activity

The means and standard deviations of 15-second epoch counts for each of the activities are summarised in Table 12.

| Table 12. Actical 15s Epoch Counts for Different Activities by Age Group. Mean (SD). |
|----------------------------------------|---|---|---|---|---|---|
| Activity                | 3  | 4     | 5     | 6     | 7     | Total   |
| Sleep                   | 1 (6) | 0 (0) | -     | -     | -     | 0 (4)   |
| Play Doh                | 18 (69) | 25 (75) | 8 (25) | 15 (48) | 26 (88) | 18 (65) |
| Puzzle                  | 24 (83) | 43 (106) | 19 (74) | 8 (38) | 8 (27) | 21 (74) |
| Puzzle                  | 24 (127) | 24 (81) | 13 (45) | 14 (57) | 29 (110) | 22 (90) |
| Draw                    | 20 (88) | 33 (121) | 18 (78) | 25 (76) | 37 (144) | 26 (103) |
| Read                    | 34 (90) | 36 (99) | 20 (65) | 29 (84) | 21 (59) | 28 (81) |
| Toy Car                 | 79 (138) | 105 (200) | 68 (98) | 80 (137) | 92 (140) | 84 (148) |
| Nintendo Wii            | 295 (438) | 227 (484) | 395 (519) | 385 (499) | 609 (532) | 362 (508) |
| Free Play               | 272 (325) | 332 (401) | 330 (395) | 266 (361) | 538 (514) | 335 (403) |

The activity counts observed for all activities were not different between the age groups. Therefore all 15-second epoch counts were pooled together for each activity (Figure 12). As can be seen in Figure 12, the 15-second epoch count distributions for the activities fall into four statistically significantly different bands.
4.5 Cut-off Derivation

A ROC curve was plotted using accelerometer measurements from the 5 sitting SBs from all age groups to determine the best cut-off for discriminating SB from non-SB (Toy Car, Nintendo Wii and Free Play). Sleep was not included in the ROC curve analysis due to having a significant by different mean count and dispersion. Multiple cut-offs were identified and sensitivity and specificity for each cut-off were calculated based on their discriminating power. In this context, sensitivity was the rate at which SB was correctly identified while specificity was the rate at which non-SB was correctly identified. The ROC curve was then plotted with sensitivity along the y-axis and 1-specificity on the x-axis (Figure 13).
The diagonal line intersecting (0.00,0.00) and (1.00,1.00) indicates no significant discrimination between an event versus nonevent e.g. SB vs. non-SB. The more skew towards the point (1.00, 0.00) the curve is, the higher the combined sensitivity and specificity are, indicating superior discriminating power. The latter is indicated by the ‘area under the curve’, with 1.0 indicating maximal performance and 0.50 indicating no meaningful discriminating power. In the current study, the curve shows significant skew towards the point (1.00, 0.00) and the area under the curve is high (=0.843, 95% CI=0.836-0.851), indicating excellent discriminating power of the SB cut-off derived. Three cut-offs with the highest combined sensitivity and specificity were tabulated to illustrate the cut-off selection process. These three cut-offs are circled in the ROC curve (Figure 13).

<table>
<thead>
<tr>
<th>Count/15s</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-47</td>
<td>89.55</td>
<td>62.05</td>
</tr>
<tr>
<td>0-45</td>
<td>89.24</td>
<td>62.77</td>
</tr>
<tr>
<td>0-40</td>
<td>88.44</td>
<td>64.63</td>
</tr>
</tbody>
</table>
Compared to values of 45 and 47 counts per 15 seconds, the value of 40 provided the highest combined sensitivity and specificity (88.44% and 64.63%). The value of 40 counts per 15 second is therefore the chosen cut-off for SB.

4.6 Validity and Cross-Validation

For the 9 children who had the CARS assessed during free play, the CARS score and the associated Actical counts are shown in Figure 14. The correlation between Actical counts and CARS score was moderate with $r_p=0.56$.

Comparison against DO of the proportion of SB estimated by the Actical was carried out and the results are shown in Table 13. Paired $t$ test carried out to compare the two sets of estimates obtained the probability of 0.055, which was statistically non-significant. This meant that the mean of differences between the SB proportions estimated was 8.4%, however this was not statistically significant. To examine the data visually, proportion of SB (%) predicted by the cut-off was plotted against SB measured by DO (Figure 15). It appears that the Actical cut-off underpredicted SB in relation to the level measured by CARS.
Table 13. Estimated proportions of SB (%) by the criterion measure and Actical accelerometer.

<table>
<thead>
<tr>
<th>Child</th>
<th>Proportions of SB (%)</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CARS</td>
<td>Actical</td>
</tr>
<tr>
<td>1</td>
<td>56.3</td>
<td>25.0</td>
</tr>
<tr>
<td>2</td>
<td>18.8</td>
<td>6.3</td>
</tr>
<tr>
<td>3</td>
<td>53.8</td>
<td>53.8</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>6.7</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>43.8</td>
<td>25.0</td>
</tr>
<tr>
<td>7</td>
<td>56.3</td>
<td>50.0</td>
</tr>
<tr>
<td>8</td>
<td>56.3</td>
<td>50.0</td>
</tr>
<tr>
<td>9</td>
<td>15.4</td>
<td>7.7</td>
</tr>
<tr>
<td>Mean</td>
<td>33.4</td>
<td>24.9</td>
</tr>
</tbody>
</table>

Figure 15. Relationship between sedentary behaviour measured by CARS and Actical.
CHAPTER 5: DISCUSSION

5.1 Actical Accelerometer Counts of Physical Activities

This study identified ranges of 15-second epoch counts associated with performing several common activities seen in children 3 to 7 years of age. These activities were purposely chosen to encourage participants to perform sedentary level movement (‘Sleep’, ‘Draw’, ‘Play Doh’, ‘Puzzle’, ‘Read’, ‘TV’), light level activities (‘Toy Car’), activities of higher intensities (‘Nintendo Wii’), and ‘Free Play’. These served as observations for a wide range of PA carried out in an unstructured setting for validation purposes, as well as for cross-validation of the derived cut-off of SB. The three groups turned out to have significantly different accelerometer count ranges.

The Actical is the newest omnidirectional accelerometer available commercially, which detects movement in multiple planes. This technological advantage is potentially capable of enhancing the accuracy of accelerometer measurement. Currently there has only been one study reporting the Actical accelerometer in preschool children. Pfeiffer et al\(^{[16]}\) used the Actical to measure PA in 18 preschool children who had a mean age of 4.4 years (SD=0.7, range 3.4-5.7). Demographic information by means and standard deviations were: height 105.1 (7.5) cm, weight 18.8 (5.6) kg, BMI 16.7 (2.6) kg.m\(^{-2}\). Table 14 summarises the counts by activity from the study.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Actical count per 15s. Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resting</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Slow walk (2 mph)</td>
<td>479.6 (98.7)</td>
</tr>
<tr>
<td>Brisk walk (3mph)</td>
<td>971.1 (234.0)</td>
</tr>
<tr>
<td>Jog (4 mph)</td>
<td>1746.9 (556.1)</td>
</tr>
</tbody>
</table>
There have been two other studies reporting Actical counts for selected activities in children of older age groups (Figure 16). In a study by Heil\cite{329} 24 children aged 8-16 years were studied while in a study by Puyau \textit{et al}\cite{201} 32 children aged 7-18 years were studied. Participants in both studies performed a number of selected activities under controlled laboratory settings while wearing the Actical accelerometer around their hips. Unlike in the current study, the activity counts from these two studies were reported in counts per minute. Activity counts per 15 second were converted into counts per minute to allow for comparisons between the studies. It was noted that despite the age difference, the sitting activity counts from the current study and Heil\cite{329} were comparable. Similar to the current study, the activity counts for children of different ages were found to be comparable.
Figure 16. Actical accelerometer counts by activity, from published studies. N.B. Actical counts are expressed in counts per minute. Activity counts measured in 15 second epochs were converted to counts per minute by multiplying by 4.
5.2. Actical Accelerometer Cut-Off for SB

There is no formally published Actical accelerometer cut-off for SB in 3-5 year old children to-date. However two studies have reported cut-offs for the Actical accelerometer for measuring PA in children. Using indirect calorimetry as criterion measure, Pfeiffer et al\(^{[16]}\) has found cut-offs for 3-5 year old children for MVPA and VPA, results of which were published. Although not formally published, through personal communication with the author they reported the cut-off of SB to be <35 counts/15s (Table 15).

<table>
<thead>
<tr>
<th>Study</th>
<th>Sample</th>
<th>Criterion measure</th>
<th>Cut-offs (counts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pfeiffer et al(^{[16]})</td>
<td>N=18, 7 boys, 11 girls, 3-5 yrs</td>
<td>Portable indirect calorimetry</td>
<td>LPA: ≥35/15s</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>MPA: ≥715/15s,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>VPA: ≥1411/15s.</td>
</tr>
<tr>
<td>Puyau et al(^{[20]})</td>
<td>N=32, 14 boys, 18 girls, 7-18 yrs</td>
<td>Room respiration calorimetry</td>
<td>LPA: ≥100/min</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>MPA: ≥1500/min</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>VPA: ≥6500/min</td>
</tr>
</tbody>
</table>

The cut-off for SB of <35 counts/15s is very similar to that of the current study. This may be due to several reasons as follows: similar age range 5 of the study participants, similar means of height, sedentary-level activities employed to derive the cut-offs, and finally the accelerometer epoch settings were also similar. In Pfeiffer et al\(^{[16]}\)’s study, accelerometer counts were extracted corresponding to the period of steady states of activity, whilst in the current study, which observed high adherence rates for the sedentary-level activities performed, the activity counts were considered to closely resemble counts that could have been obtained from steady states of activity. Interestingly, Pfeiffer et al\(^{[16]}\) also did not observe age-related count differences, and similarly they analysed the PA measurements for the participants as a whole. Despite the similarities in the cut-offs between Pfeiffer et al\(^{[16]}\)’s work and the current study, there were several notable differences between the two studies. For example, it is conceivable that the portable calorimetry system used in Pfeiffer et al\(^{[16]}\)’s study (as of most other portable calorimetry systems) could have incurred significant interference with activity, especially in children. This means the participants could have performed the activities differently than usual due to equipment constraints and/or emotional stress\(^{[288]}\).
In another study, Puyau et al.\textsuperscript{[201]} studied Actical accelerometer counts in 32 children aged 7-18 years who performed a range of activities in a respiration calorimetry chamber. Using the ROC curve analysis, they found the cut-off for SB to be <100 counts/min (sensitivity = 86\%, specificity = 72\%). Compared with their SB cut-off, the current study’s cut-off is higher after unit conversion to counts per minute by multiplying by 4 (e.g. 40 counts/15s × 4=160 counts/min). However whether unit conversion of epoch length by multiplication is an appropriate method remains to be clarified. In their study, Puyau et al.\textsuperscript{[201]} collected accelerometer count in 1-minute epochs and this could have been a factor accounting for the different cut-offs between the two studies. It has been proposed that due to young children’s intermittent nature with their PA patterns, using a shorter epoch duration could more accurately reflect their behaviour pattern\textsuperscript{[179-180, 264]}. For example, in a given minute a child might engage in a short bout of non-sedentary activity which lasted less than 10 seconds and spend the rest of the minute performing sedentary level activities. This intermittent, short-lasting bout of non-sedentary activity would be masked by way of averaging the accelerometer output with SBs which would in turn underestimate the overall minute the child spends in non-sedentary activities. Thus, in the setting of cut-off derivation, lower the associated cut-off. In addition, Puyau et al.\textsuperscript{[201]}’s study recruited children of an older age group than the current study, which is another likely factor for the cut-off difference. It has been documented by some researchers that using one cut-off for all children could erroneously result in the younger children being estimated as having been less active\textsuperscript{[299]}. On the other hand, some studies have not identified differences in accelerometer output between children aged 3 and aged 5 years\textsuperscript{[11, 13]}, as is the case in the current study. It is unknown whether age itself or other unknown moderating factors could be responsible for any accelerometer count differences observed by some researchers. However it has been hypothesised that variables which moderate the vertical displacement, as recorded primarily by all accelerometers, could affect accelerometer counts. Potential variables such as height, leg length, coordination or maturational age could all affect the vertical displacement of body during activity and the effects of these variables remains to be deciphered.

5.3 Reliabilities of the Actical Accelerometers

In the current study, the level of agreement between accelerometers was defined based on investigator’s experience with the Actical accelerometer count magnitudes and differences were considered to be trivial if it was less than 5\%, small if less than 15\%, moderate if less than 20\% and large if greater than 25\%, of averaged counts. Analysis on agreement has shown that intra-instrument agreement was high and differences were less
than 5-10%. Such findings suggest that the individual Actical accelerometer works reliably on its own. On the other hand, inter-instrument agreements were more variable. Figure 17 illustrates the varying counts obtained from a randomly selected batch of Actical accelerometers.

![Graph showing counts per 15s for different speeds across six Actical accelerometers.]

**Figure 17. Comparisons of Six Randomly Selected Actical Accelerometers.**

Several factors could contribute to the inter-instrument differences. Firstly concerning the Actical accelerometers, battery life and monitor calibration could have been influential. Battery life was regularly checked during the study throughout the data collection phase to minimise this potential source of technical error. The monitor calibration of Actical hereby refers to the precision of Actical against a gold standard (determined by Mini-Mitter Actical) which if altered requires the accelerometers to be calibrated back to satisfactory precision. The precision of Actical is likely to decrease over time and Mini-Mitter Actical has recommended that the accelerometer is returned to the company every two years for maintenance and calibration. During the study the individual monitor calibration was difficult to judge without a reference to compare to. However, differences between monitor performance were obvious during the study. This is inspite of only
Acticals from a newer batch, issued to the investigators in 2008, being used to attempt to minimise error associated with decreased precision. Thirdly, although the custom-made ‘motion generator’ was designed to generate identical motion, it is by no means flawless and there may have been slight differences in motion exerted to the Acticals. However we have observed little change in Actical counts through repeated testing with Acticals placed at different slots on the monitor mount, as shown in the high intra-monitor agreement.

The reliability of Actical accelerometers over time has not been formally reported in peer-reviewed journals, however unpublished results by Pfeiffer et al\[^{16}\] has shown an acceptable inter-instrument reliability coefficient ($r=0.92$). However there was no inter-instrument agreement reported in their study. Currently published reports on reliability are available for the Actigraph, Actiwatch and Caltrac accelerometers. De Vries et al\[^{333}\] conducted a systematic review on motion sensors which has been updated recently\[^{14}\]. These two systematic reviews identified in total 17 studies that reported reliability of accelerometers (Table 16). Studies evaluating the reliability have either compared results from two accelerometers placed at different sites such as between left and right hips (especially for evaluating inter-instrument reliability) or from multiple days of measurement. Strength of reliability was often indexed by calculating a certain kind of correlation coefficient or by calculating the differences between average counts. For the Caltrac accelerometer, results on the intra-instrument reliability have ranged from low ($r_{p,2d}=0.30$) to moderate ($r_{p,2d}=0.53-0.69$) and high ($ICC_{2d}=0.76$). In comparison, inter-instrument reliability for Caltrac was high in both field and laboratory settings\[^{334}\] and the reported mean difference in another study was only $0.8\pm0.5\%$\[^{335}\]. The inter-instrument reliability of the Actiwatch was examined by one study which observed a high correlation ($r_{p,b,i}=0.93$). The Actigraph once again has the largest evidence base on reliability, which has been thoroughly tested across a wide range of age groups in both field and laboratory settings. The intra-instrument reliability between days of examination has been low to moderate with $r_p$ ranged between $0.23-0.53$. Similarly accelerometer reliability using 1 monitored day to represent usual PA was low to moderate with $ICC=0.31-0.55$, however when number of monitoring days taken into account was increased, $ICC$ increased to $0.71-0.90$. Using accelerometer counts obtained from different sites of placement, inter-instrument reliability has been shown to be high with $ICC$ ranging between $0.77-1.0$. 

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<table>
<thead>
<tr>
<th>Accelerometer</th>
<th>Study</th>
<th>Sample</th>
<th>Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>N=35; 8-13 yo</td>
<td>Intra-: $r_{p,2d}=0.30$ (non-significant); Inter-: $r_{p,1-l,field}=0.96$; $r_{p,l-r,lab}=0.89$</td>
</tr>
<tr>
<td>Caltrac</td>
<td>Sallis et al[334]</td>
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<tr>
<td></td>
<td>Bray et al[335]</td>
<td>N=40; 10-16 yo</td>
<td>Inter-: difference $c_{1-r}=0.8\pm0.5%$</td>
</tr>
<tr>
<td></td>
<td>Raudsepp and Pall[336]</td>
<td>N=42; 8-9 yo</td>
<td>Intra-: $r_{sp,2d}=0.53-0.69^{**}$</td>
</tr>
<tr>
<td></td>
<td>Allor and Pivarnik[337]</td>
<td>N=46; 12.0±0.6 yo</td>
<td>Intra-: ICC $1d=0.61$; ICC $2d=0.76$</td>
</tr>
<tr>
<td></td>
<td>Puyau et al[298]</td>
<td>N=26; 6-16 yo</td>
<td>Inter-: $r_{p,h-l}=0.93$</td>
</tr>
<tr>
<td>Actiwatch</td>
<td>Janz[338]</td>
<td>N=31; 7-15 yo</td>
<td>Intra-: $r_{p,3d}=0.23-0.53^*$</td>
</tr>
<tr>
<td></td>
<td>Janz et al[339]</td>
<td>N=30; 7-15 yo</td>
<td>Intra-: ICC $1d=0.42^{<em>}$; ICC $6d=0.84^{</em>}$</td>
</tr>
<tr>
<td></td>
<td>Trost et al[340]</td>
<td>N=381; 6-18 yo</td>
<td>Intra-: ICC $1d=0.31$; ICC $7d=0.87$</td>
</tr>
<tr>
<td></td>
<td>Benefice and Cames[341]</td>
<td>N=40; 13.3±0.5 yo</td>
<td>Intra-: ICC $1d=0.55$; ICC $4d=0.71$</td>
</tr>
<tr>
<td></td>
<td>Garnier and Benefice[342]</td>
<td>N=40; 13-15 yo</td>
<td>Intra-: ICC $1d=0.49$; ICC $8d=0.90$</td>
</tr>
<tr>
<td></td>
<td>Toschke et al[343]</td>
<td>N=192; 5-6 yo</td>
<td>Intra-: $r_{p,5d}=0.31-0.51$</td>
</tr>
<tr>
<td></td>
<td>Trost et al[344]</td>
<td>N=30; 10-14 yo</td>
<td>Inter-: ICC $1-5=0.87$</td>
</tr>
<tr>
<td></td>
<td>Fairweather et al[286]</td>
<td>N=10; 4.0±0.04 yo</td>
<td>Inter-: mean difference $c_{l-r} (95% CI)=31 (1-61)$; $r_{p,l-r}=0.92^{**}$</td>
</tr>
<tr>
<td></td>
<td>Puyau et al[298]</td>
<td>N=26; 6-16 yo</td>
<td>Inter-: $r_{p,h-l}=0.77$</td>
</tr>
<tr>
<td></td>
<td>Nilsson et al[180]</td>
<td>N=16; 7.5±0.3 yo</td>
<td>Inter-: mean difference $c_{h-b} (95% CI)=22 (-110-154)$; $r_{p,h-b}=0.81^{**}$</td>
</tr>
<tr>
<td></td>
<td>Garcia et al[345]</td>
<td>N=16; 6-10 yo</td>
<td>Inter-: ICC $1-b=0.86$</td>
</tr>
<tr>
<td></td>
<td>Sirard et al[288]</td>
<td>N=16; 3-5 yo</td>
<td>Inter-: ICC $1-5=0.84$</td>
</tr>
<tr>
<td></td>
<td>Treuth et al[300]</td>
<td>N=74; 13.4-15.4 yo</td>
<td>Inter-: $r_{1-5}=1.0$</td>
</tr>
</tbody>
</table>

Abbreviations: $r_{sp}$, Spearman’s rank order correlation coefficient; l–r, left versus right hip; h–l, hip vs. lower leg; h–b, hip vs. lower back; CV, coefficient of variation; d, day, yo, year old. *$p<0.05$. **$p<0.01$. 

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Although high inter-instrument reliability has been observed by researchers for Caltrac, Actiwatch and Actigraph, the current evidence base is insufficient to draw any firm conclusions. In addition, considerations need to be given to potential confounding variables which could potentially influence accelerometer counts. For example, the different site of accelerometer placement is a perceivable variable and the right hip has been the preferred site of placement for the Actigraph\textsuperscript{14}. Studies however have shown no significant difference between different sites (left vs. right hip\textsuperscript{1286, 344}, hip vs. lower back\textsuperscript{180}, hip vs. lower leg\textsuperscript{298}). Another important issue lies in the method of testing reliability. Correlational analysis is potentially problematic in assessing the reliability of monitors. In essence, correlation refers to the strength of relationship between measurement tools per se, which is different to agreement where the outcome of interest is how exactly identical the monitor outputs are. In the current study, Pearson’s product-moment correlation coefficients were calculated which showed $r_p=1.0$ for both intra- and inter-instrument reliability, however when agreement was examined by plotting Bland-Altman curves, significant differences were observed between the instruments (ranged from $<10\%-50\%$). Such a finding suggests that when more than one Actical accelerometer is used to assess and compare counts between persons, any differences may be exaggerated from inter-instrument measurement errors. The significant disagreement between the Acticals meant that the accuracy of results from the current study may be less and inadequate for measuring PA levels at an individual level unless a calibration instrument becomes available to ensure that one Actical is performing the same as others. Therefore, the cut-off derived may be more suitable for use in a group of children rather than at an individual level. This is in keeping with the observations made by previous studies on the application of accelerometers.

### 5.4 Actical Accelerometer Validity

Correlation between the Actical accelerometer and DO using CARS was moderate ($r_p=0.56$). Previous publication of Actical validity tests through simultaneous PA measurement using calorimetry as the criterion measure have obtained higher correlation ($r=0.86-0.89$\textsuperscript{16, 291}). However, these high correlations were observed under laboratory settings where the participants performed prescribed activities and steady states were acquired. When the validity test was performed based on unstructured free play at participants’ preschool, the ICC found was 0.59 using indirect calorimetry as the criterion measure\textsuperscript{16}. The Actical seems to consistently perform at a higher correlation with criterion measure in the laboratory setting compared to unstructured free play. Validity tests conducted within similar settings appear to be very comparable regardless of the
type of criterion measure used. Few studies have performed a cross-validation of their accelerometer count cut-offs. In a study by Pfeiffer et al[16], EE predicted from unstructured free play based on accelerometer counts reached acceptable limits of agreement, although accelerometer measurement under predicted VO₂ in relation to the measured values by indirect calorimetry. The current study also observed a non-significant difference of estimated SB proportions by accelerometer and DO. A tendency to under predict SB was also observed.

5.5 Study Strengths and Limitations

The present study had a number of strengths. The study recruited a sample of moderate size for cut-off derivation. Participants also had comparable demographic features with children from the rest of New Zealand, which enhanced the external validity of the cut-off derived. Secondly, the structured activities were performed in their preschool or school environment where the participant would feel comfortable, and where research environment related confounders were minimised. Participants and the researcher also interacted closely which was reflected by the high compliance rate. Finally, the study utilised a motion generator to assess reliability of accelerometer.

The present study had a number of limitations. The study participants were mainly recruited from one preschool and primary school in Dunedin, New Zealand. Selection bias could have existed from this recruitment method. For example, many children recruited from the preschool were grown up in socio-economic environment. Socio-economic status is known to associate inversely with weight status across population, and could in turn be influential to the habitual PA level. There could be potential confounders to influence participants’ activity pattern, for example the study was spread across two sessions for a number of participants; children who participated in the study programme in the afternoon may not be as energetic as they are in the morning; and the effect of having the presence of a friend as opted by the participant. However, throughout the study the researchers have ensured that children were comfortable and enthusiastic about participating in the study, regardless of whether their friend was present or not. The study observed moderate validity and cross-validation showed that SB estimated using the Actical was within an acceptable range. However the sample size for comparison with DO was small (N=9). Next, despite training was carried out with administering CARS, more training may have been required to ensure optimal administration. Also, it would have been cautious to include simultaneous coding and calculation of inter-rater reliability. Finally, the cut-off derived from the study was limited.
by a wide inter-instrument agreement range, therefore application of the derived cut-off is advised for analysis of SB level in groups of children only.

5.6 Future Research and Recommendations

The study has identified several needs which could be pursued during future research. These apply especially for research conducted in New Zealand using the Actical accelerometers. The main points include:

- Minimising effect from selection bias by recruiting future study participants from a less confined study population e.g. from different preschools and schools in the local town/city.
- Improving the validity test protocol with a larger sample and with more stringent training protocol on using the CARS. Inclusion of cross-validation with a large sample in the study protocol could aid in assessing the performance under free-living settings, which is an important bridge prerequisite for application for public health purposes.
- Monitoring the reliability of the Actical accelerometer, especially inter-instrument reliability. The inter-instrument reliability of newly calibrated Actical accelerometers released from Mini-Mitter should be evaluated and their performance monitored repeatedly during the two year course, to minimise any lowered precision that may occur due to frequent use. Precision could also be improved by scheduled service and calibration of the accelerometers during the course of its use. However not being able to purchase a calibrator from the manufacturer limits this option.
- An alternative approach may be considered, that is to describe the cut-off in relative terms, for example, counts >50% of the range of counts classified as MVPA. This approach however would require the extra step of Actical range assessment, which may limit its use in large population based studies.

For future study designs for the Actical accelerometer in general, the following points should be taken into consideration:

- The current evidence base on the validity and reliability of the Actical in children aged 3-5 year old is sparse and future studies are required to demonstrate the reproducibility of this motion sensor.
- Very few accelerometers have been used on children less than 3 year old. Preliminary studies exploring the utility, feasibility and validity of different types of accelerometers in children under 3 years of age are awaited to assess the use of this technology in infants and toddlers.
Finally, intervention studies investigating the relationship between PA, SB and energy balance in preschool children, have been rare. Intervention studies would be the important next step in assessing the effectiveness of the current PA, SB guidelines, developing recommendations to refine the current guidelines, and providing potential public health strategies to address the obesity epidemic.

5.7 Conclusion

This study has provided additional evidence on the performance of the Actical accelerometer in children aged 3 to 7 years. The count ranges obtained from carrying out several common activities in preschool children, the reliability and validity tests of the Actical, and the derived cut-off for SB, allow for gauging the performance of the Actical across the studies. Despite the differences in certain demographic features of the study sample, the criterion measure used and the setting in which the study was carried out, the results from this study have indeed shown several similarities with the current evidence base: validity under unstructured free play circumstances, activity count ranges and the SB cut-off with a previous unpublished cut-off in 3-5 year old children. The study has also identified certain internal variability in the performance of the Actical using the custom-made motion generator. Understanding these attributes would allow the scientific community to assess how applicable the Actical is for use in the health sector, at both the individual and population levels. This study has confirmed that while using the Actical at individual level is unadvisable at this stage, it may be the most useful all-round device we have thus far for measuring PA in a group of preschool children. Further, the results from this study have indicated that the Actical is capable of discriminating SB from other levels of PA and such a cut-off could be useful in identifying groups of people having high levels of SB, which in turn predicts higher risks for gaining excessive weight.
REFERENCES


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123. Gunnes M, Lehmann EH. Physical activity and dietary constituents as


305. Grontved A, Pedersen GS, Andersen LB, Kristensen PL, Moller NC, Froberg K. Personal characteristics and demographic factors associated with


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## APPENDIX A

Prevalence of physical activity in children aged 5 years or younger.
Modified from: Okely *et al*[154].

<table>
<thead>
<tr>
<th>Author</th>
<th>Study sample*</th>
<th>Physical activity type/measure</th>
<th>Prevalence</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Actigraph accelerometer</strong></td>
<td></td>
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<tr>
<td>Alhassan <em>et al</em>[346]</td>
<td>USA: 32 Latino children, mean age (SD)=3.6 (0.5) years</td>
<td>Actigraph accelerometers (30s epoch): 4 weekdays, mean time worn: 780 mins (control); 755 mins (intervention)</td>
<td>% LPA: 3.9%</td>
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<tr>
<td></td>
<td></td>
<td>LPA-3 years: 1205-2456; 4 years: 1453-3244; 5 years: 1593-3560 MVPA-3 years: ≥2457; 4 years: ≥3245; 5 years: ≥3561</td>
<td>% MVPA: 1.7%</td>
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<td></td>
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<td>% time worn LPA</td>
<td>CPM: 243</td>
</tr>
<tr>
<td></td>
<td></td>
<td>% time MVPA</td>
<td></td>
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<td></td>
<td></td>
<td>CPM</td>
<td></td>
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<tr>
<td><strong>Ball <em>et al</em>[220]</strong></td>
<td>Australia: 168 children (52% boys), age: 5-6 years</td>
<td>Actigraph accelerometers: 4 days, included 1 weekend day</td>
<td>Total counts/day (×1000)</td>
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<td></td>
<td></td>
<td>Average counts/day</td>
<td>Boys: 527.6±112.8</td>
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<tr>
<td></td>
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<td>min/day MPA (3.0-5.9 METs)</td>
<td>Girls: 467.4±111.0</td>
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<td></td>
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<td>min/day VPA (≥6.0 METs),</td>
<td>MPA:</td>
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<td></td>
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<td></td>
<td>Boys: 232.0±41.2</td>
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<td></td>
<td></td>
<td></td>
<td>Girls: 223.1±42.1</td>
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<td></td>
<td></td>
<td></td>
<td>VPA:</td>
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<td></td>
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<td>Boys: 45.6±18.0</td>
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<td></td>
<td></td>
<td></td>
<td>Girls: 33.6±12.5</td>
</tr>
</tbody>
</table>
### Prevalence of physical activity in children aged 5 years or younger (continued).

<table>
<thead>
<tr>
<th>Author</th>
<th>Study sample*</th>
<th>Physical activity type/measure</th>
<th>Prevalence</th>
</tr>
</thead>
</table>
| Cardon and De Bourdeaudhuij\[224]\ | Belgium: 76 children (39 girls), age: 4-5 yo | Actigraph accelerometers (15s epochs): 2 weekdays and 2 weekend days, waking hrs mean (SD)=11.8 (1.5) hr/day, range: 8.6-15.2 hrs  
CPM  
% LPA (4yo: 364-811 and 5yo: 399-890, counts/15s)  
% MPA (4yo: 812-1234 and 891-1254, counts/15s)  
% VPA (4yo: ≥1235 and 5yo: ≥1255, counts/15s) | CPM  
Weekdays: 738±81  
Weekend: 662±94  
Average: 701±74  
% LPA=10.5%  
% MPA=2.4%  
% VPA=2.4% |
| Fisher et al\[347]\ | Scotland: 209 children (48% boys). 104 children with mean age (SD)=3.4 (0.2) years; 105 children with mean age (SD)=5.4 (0.2) years | Actigraph accelerometers (1-min epochs): younger children 3 days included one weekend day; older children 7 days; across 4 seasons, mean time worn=56.6 hrs  
% time LPA (1100-3200 CPM)  
% time MVPA (>3200) CPM | % LPA: 19.6%  
% MVPA: 3.2%  
CPM: 781 |
| Fisher et al\[348\], Kelly et al\[349\] | Scotland: 394 children, mean age (SD)=4.2 (0.5) years | Actigraph accelerometers (1-min epochs): 6 days 56 hrs total wearing time  
% time LPA (1100-3200 CPM)  
% time MVPA (>3200) CPM | % LPA: 20.3%  
% MVPA: 3.4%  
CPM: 769±192 |
| Grøntved et al\[305\] | Denmark: 146 children (80 girls), age: 3-6 yo  
3-4: 44 children  
4-5: 50 children  
5-6: 52 children | Actigraph accelerometers (15s epoch): ≥3 days of ≥3 hrs at preschool. Mean (SD) wearing time: 4.5 (0.7) days, 7.1 (0.8) hrs/day  
CP epoch (15s)  
% in MVPA .(≥420 counts/15 s) | CP epoch (15s): 230.1±68.7  
% MVPA: 17.6±5.6 |
<table>
<thead>
<tr>
<th>Author</th>
<th>Study sample*</th>
<th>Physical activity type/measure</th>
<th>Prevalence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heelan and</td>
<td>USA: 100 children (48% boys), age: 4-7 years</td>
<td>Actigraph accelerometers, ≥4 days included 1 weekend day</td>
<td>MPA: 241.5±48.8 mins/day</td>
</tr>
<tr>
<td>Eisenmann[350]</td>
<td></td>
<td>MVPA ≥615 CPM</td>
<td>VPA: 32.3±17.1 mins/day</td>
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<td></td>
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<td></td>
<td>MVPA: 273.8±59.1 mins/day</td>
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<td></td>
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<td>MVPA mins/day</td>
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<td>VPA mins/day</td>
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<td>MVPA mins/day</td>
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<tr>
<td>Jackson et al[351]</td>
<td>Scotland: 104 children (50% boys), mean age (SD) boys=3.8 (0.4) years; mean</td>
<td>Actigraph accelerometers (1-min epochs): 2 weekdays and 1 weekend day ≥6 hrs/day</td>
<td>Boys: 777±207 CPM</td>
</tr>
<tr>
<td></td>
<td>age (SD) girls=3.7 (0.4) years</td>
<td></td>
<td>Girls: 651±172 CPM</td>
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<td>Average: 714 CPM</td>
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<tr>
<td>Janz et al[321, 352]</td>
<td>USA (birth cohort recruited from 8 hospitals): 2001-368 children (49% boys);</td>
<td>Actigraph accelerometers (1-min epochs): 8 hrs/day, 4 days-including weekend day</td>
<td>Boys: 766±176</td>
</tr>
<tr>
<td></td>
<td>2002-434 children (47% boys)</td>
<td></td>
<td>Girls: 701±160</td>
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<tr>
<td></td>
<td>Mean age boys: 5.2±0.4 years</td>
<td></td>
<td>Average: 733 CPM</td>
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<tr>
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<td>Mean age girls: 5.3±0.4 years</td>
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<td>Author</td>
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<td>Prevalence</td>
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<tr>
<td>Janz et al[327]</td>
<td>USA: 436 children (47% boys), age 4-7 years (mean age=5.2 years)</td>
<td>Actigraph accelerometers (1-min epochs): 8 hrs/day, 4 days-including weekend day, average wearing time 723 mins/day</td>
<td>MPA Boys: 267±44 mins/day Girls: 262±44 mins/day</td>
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<tr>
<td></td>
<td></td>
<td>MPA MVPA (≥527 CPM) VPA (≥2818 CPM) % time MVPA</td>
<td>VPA Boys: 38±19 mins/day Girls: 28±14 mins/day</td>
</tr>
<tr>
<td></td>
<td></td>
<td>% MPA: 2.2%</td>
<td>Average MVPA: 298 mins/day %MVPA: 41.2%</td>
</tr>
<tr>
<td>Kelly et al[353]</td>
<td>Scotland: 42 children (50% boys), mean age=3.8 years</td>
<td>Actigraph accelerometers (1-min epochs): 3 days included a weekend day, ~10.1 hrs/day</td>
<td>% MVPA: 2.2%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>% time MVPA (&gt;3200 CPM) CPM</td>
<td>CPM: 669±163</td>
</tr>
<tr>
<td>Lucas and Schofield[354]</td>
<td>New Zealand : 78 children, age : 3-5 years</td>
<td>Actigraph accelerometers: ≥18 hrs of monitoring</td>
<td>% LPA: 18%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>% time LPA % time MVPA</td>
<td>% MVPA: 6%</td>
</tr>
<tr>
<td>Author</td>
<td>Study sample*</td>
<td>Physical activity type/measure</td>
<td>Prevalence</td>
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<tr>
<td>Metallinos-Katsaras <em>et al</em>[^355^]</td>
<td>USA: 56 children, age: 2-5 years</td>
<td>Actigraph accelerometers (1-min epochs): 4.7-7 days, mean wearing time: 683 mins/day</td>
<td>LPA: 416.2±75.9 mins/day</td>
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<tr>
<td></td>
<td></td>
<td>LPA mins/day (&lt;615 CPM)</td>
<td>MPA: 243.7±50.1 mins/day</td>
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<td>MPA mins/day (615-2971 CPM)</td>
<td>VPA: 24.5±13.9 mins/day</td>
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<td></td>
<td></td>
<td>VPA mins/day (2972-5331 CPM)</td>
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<tr>
<td></td>
<td></td>
<td>% time LPA, MPA, VPA</td>
<td>%LPA: 60.8%</td>
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<tr>
<td></td>
<td></td>
<td>CPM</td>
<td>%MPA: 35.3%</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>%VPA: 4%</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>CPM: 744±165.7</td>
</tr>
<tr>
<td>Mickle <em>et al</em>[^356^]</td>
<td>Australia: 33 children (52% boys), mean age (SD)=4.3 (0.6) years</td>
<td>Actigraph accelerometers (1-min epochs): ≥6 hrs/day, 7 days</td>
<td>CPM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CPM</td>
<td>Boys: 911±254</td>
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<td>CPM</td>
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<td></td>
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<td></td>
<td>Girls: 809±133</td>
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<td></td>
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<td>CPM</td>
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<td></td>
<td></td>
<td>Average: 860 CPM</td>
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<td></td>
<td></td>
<td></td>
<td>% MVPA</td>
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<td></td>
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<td></td>
<td>Boys: 6.0±4.5</td>
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<td>Girls: 3.9±2.5</td>
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<td>Average: 5%</td>
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</tbody>
</table>
Prevalence of physical activity in children aged 5 years or younger (*continued*).

<table>
<thead>
<tr>
<th>Author</th>
<th>Study sample*</th>
<th>Physical activity type/measure</th>
<th>Prevalence</th>
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</thead>
<tbody>
<tr>
<td>Montgomery <em>et al</em></td>
<td><strong>Scotland</strong>: 104 children (50% boys; 36 preschoolers, 68 school-aged children) Age: (combined sample) Boys: 5.6 years Girls: 5.4 years</td>
<td>Actigraph accelerometers (1-min epochs) 5-10 hrs/day; 3 day preschoolers, 7-10 days school-aged children CPM % time in LPA (1100-3200 CPM) % time in MVPA (&gt;3200 CPM)</td>
<td>CPM Boys: 848 (398-1328) CPM Girls: 719 (332-1154) CPM Average: 784 CPM % LPA Boys: 23 (9-33) Girls: 18 (6-34) Average: 20.5% % MVPA Boys: 4 (1-14) Girls: 3 (0-8) Average: 3.5%</td>
</tr>
<tr>
<td>Pate <em>et al</em></td>
<td><strong>USA</strong>: 247 children (47% boys), 3-5 years</td>
<td>Actigraph accelerometers (15s epochs): mean 4.4 hrs/day for average of 6.6 days, range 1-11 days LPA mins/hr (1.5-2.9 METs) MVPA mins/hr (≥3.0 METs) VPA min/hr (≥6 METs)</td>
<td>Total sample LPA: 10.5±3.2 mins/hr MVPA: 7.7±3.1 mins/hr VPA: 1.9±1.1 mins/hr % LPA: 17.5% % MVPA: 13%</td>
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<tr>
<td>Author</td>
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<tr>
<td>Penpraze et al</td>
<td>Scotland: 76 children, mean age (SD)=5.6 (0.4) years</td>
<td>Actigraph accelerometers (1-min epochs): 7 days, mean 11 hrs/day for overall mean 84.5 hrs</td>
<td>CPM Boys: 870±187&lt;br&gt;Girls: 771±161&lt;br&gt;Average: 821 CPM</td>
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<tr>
<td></td>
<td></td>
<td>CPM</td>
<td>CPM weekends&lt;br&gt;Boys: 900±245&lt;br&gt;Girls: 833±219</td>
</tr>
<tr>
<td>Pfeiffer et al</td>
<td>USA: 331 children (168 boys), aged 3-5 years</td>
<td>Actigraph accelerometers (15s epochs): up to 5 weekdays and 2 weekend days MVPA (≥420 counts/15s)</td>
<td>Average MVPA: Mean (SD)=7.6 (2.1) mins/hr</td>
</tr>
<tr>
<td>Reilly et al</td>
<td>Scotland: 78 children (51% boys), age: 3 years</td>
<td>Actigraph accelerometers (1-min epochs): 3 days, mean 9.8 hrs/day CPM % LPA (1100-3200 CPM) % MVPA (&gt;3200 CPM)</td>
<td>CPM Boys: 739±178 CPM&lt;br&gt;Girls: 633±158 CPM&lt;br&gt;Total: 692±176&lt;br&gt;% LPA 18% (inter-quartile range 14-22)&lt;br&gt;% MVPA 2% (inter-quartile range 1-4)</td>
</tr>
</tbody>
</table>
## Prevalence of physical activity in children aged 5 years or younger (continued).

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Reilly et al[^294]</td>
<td>Scotland: 545 children (50% boys; intervention and control groups combined), age: 4 years</td>
<td>Actigraph accelerometers (1-min epochs): 6 days</td>
<td>Intervention group[^†]</td>
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<td></td>
<td></td>
<td>CPM</td>
<td>CPM: 732</td>
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<td></td>
<td></td>
<td>% MVPA (&gt;3200 CPM)</td>
<td>% MVPA: 2.6%</td>
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<td></td>
<td></td>
<td>Control group[^†]</td>
<td>CPM: 809</td>
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<td></td>
<td></td>
<td>% MVPA: 3.0%</td>
<td>Average</td>
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<td></td>
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<td>‡baseline data</td>
<td>CPM: 771</td>
</tr>
<tr>
<td></td>
<td></td>
<td>% MVPA: 2.8%</td>
<td>Boys: 779±230</td>
</tr>
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<td></td>
<td>Girls: 683±178</td>
</tr>
<tr>
<td>Roemmich et al[^361]</td>
<td>USA: 59 children (54% boys), age: 4-7 years. Boys: mean age (SD)=5.8 (1.3) years. Girls: mean age (SD)=6.2 (1.2) years</td>
<td>Actigraph accelerometers (1-min epochs): 4 days</td>
<td>CPM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CPM</td>
<td>Boys: 779±230</td>
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<td></td>
<td></td>
<td>Girls: 683±178</td>
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<td></td>
<td>Average</td>
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<td></td>
<td>731 CPM</td>
</tr>
<tr>
<td>Trost et al[^362]</td>
<td>USA: 245 children (48% boys), age: 3-5 years</td>
<td>Actigraph accelerometers (15s epochs): 3-11 days, mean 4.4±1.3 hrs/day</td>
<td>% MVPA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Boys: 42.2±12.8</td>
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<tr>
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<td></td>
<td></td>
<td>Girls: 39.0±12.5</td>
</tr>
</tbody>
</table>
## Prevalence of physical activity in children aged 5 years or younger (continued).

<table>
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<tr>
<td><strong>Actiwatch accelerometer</strong></td>
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<tr>
<td>Finn et al[11]</td>
<td>USA childcare centres: 10 centres, 214 children (49% boys), mean age (SD)=3.9 (0.06) years</td>
<td>Actiwatch accelerometer (1-min epochs): 48 hrs VPA (≥1000 CPM: corresponds to CARS score of 3) % time in VPA Parental proxy-report child participation in organized sport (% yes)</td>
<td>% VPA Boys: 5.2% Girls: 4.5% Participation in organized sport Boys: 20% Girls: 15%</td>
</tr>
<tr>
<td>Specker and Binkley[363]</td>
<td>USA: 178 children (53% boys), age 3–4 years</td>
<td>Activewatch accelerometers (48 hrs) (epoch length not reported) CPM % time MVPA % time VPA</td>
<td>CPM: 259,000-297,000 % MVPA: 12.1-14% % VPA: 4.5-5.4%</td>
</tr>
<tr>
<td><strong>Actical accelerometer</strong></td>
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<tr>
<td>Taylor et al[20]</td>
<td>New Zealand: 208 3yo children (95 girls), 180 4yo children (79 girls), 186 5 yo children (81 girls)</td>
<td>Actical accelerometers: 5 days (24-h monitoring) min/day MVPA</td>
<td>MVPA min/day (SD) Boys: 3yo: 40 (55) 4yo: 16 (20) 5yo: 21 (23) Girls: 3yo: 44 (53) 4yo: 17 (16) 5yo: 23 (24)</td>
</tr>
</tbody>
</table>
## Prevalence of physical activity in children aged 5 years or younger (continued).

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Temple et al</strong>[^364^]</td>
<td>Canada: 65 children (51% boys), age: 3-5 years mean age (SD)=4.0 (0.9) years</td>
<td>Actical accelerometers (15s epochs): &gt;4 hrs/day, mean time worn= 7.0 hrs/day, 1-4 days CP.epoch (15s) min/hr LPA (50 ≤LPA ≤715 counts·15 s⁻¹) min/hr MVPA (&gt;715 counts·15 s⁻¹) min/hr VPA (&gt;1411 counts·15 s⁻¹)</td>
<td>CP.epoch (15s) Boys: 107.41±36.75 Girls: 101.77±25.48 Average: 104.63±31.59 LPA: Boys: 19.24±3.89 mins/hr Girls: 18.23±4.20 mins/hr Average: 18.75±4.04 mins/hr</td>
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<td>MPA: Boys: 1.79±1.06 mins/hr Girls: 1.73±0.70 mins/hr Average: 1.76±0.90 mins/hr</td>
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<td>VPA: Boys: 0.34±0.35 mins/hr Girls: 0.29±0.22 mins/hr Average: 0.32±0.29 mins/hr</td>
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<tr>
<td><strong>Pedometry</strong></td>
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<tr>
<td>Al-Hazzaa and Al-Rasheedi[^267^]</td>
<td>Saudia Arabia: 224 children, age 3.4-6.4 years, mean age (SD)=5.2 (0.85) years</td>
<td>Yamax Digiwalker, 3 weekdays Daily step counts</td>
<td>Mean=6773 steps per day &gt;10,000 steps/day: 22.4%</td>
</tr>
<tr>
<td>Boldemann et al[^365^]</td>
<td>Sweden: 197 children, age range: 4-6 years</td>
<td>Yamax Digiwalker; ≥90% wore pedometer ≥5 days</td>
<td>Mean=6773 steps per day &gt;10,000 steps/day: 22.4%</td>
</tr>
<tr>
<td>Cardon and de Bourdeaudhuij[^12^]</td>
<td>Belgium: 122 children, mean age=4.99 (range: 4-6 years)</td>
<td>Yamax Digiwalker steps/day, steps/min 60 mins MVPA (accelerometer)=13,874 step counts</td>
<td>9980±2605 steps/day 18.7±5.3 steps/min 8% reached equivalent of 60 mins MVPA</td>
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</tbody>
</table>
### Prevalence of physical activity in children aged 5 years or younger (continued).

<table>
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<tr>
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<th>Prevalence</th>
</tr>
</thead>
</table>
| **Sigmund et al**<sup>[268]</sup> | Czech Republic: 176 children, age: 5.70±5 years | Pedometer: Yamax Digiwalker SW-200: ≥8 hrs/day, 7 days included a weekend. Daily step counts (steps/day) | Daily step count  
Weekdays: Boys: 11,864 in boys on  
Girls: 9923 steps/day  
Weekends: Boys: 11,182 steps/day  
Girls: 10,606 steps/day |
| **Observation** | **Bower et al**<sup>[243]</sup> | USA: 20 centres  
Observation System for Recording Activity in Preschools  
(OSRAP): 8×32 min periods over 2 consecutive days; observation periods excluded nap and meal times | OSRAP: 9-15% of observed time in MVPA  
Mid-range: 12% |
| **Brown et al**<sup>[244]</sup> | USA: 476 children (51% boys). Age: 3-5 years | Observational System for Recording Physical Activity in Children – Preschool Version (OSRAC– P): 5-6 hrs/child, mean±SD=327.5±29.5 min/child (inside); 34±24.5 min/child (outside).  
Inside and Outside  
% recorded intervals LPA (Activity Level 3)  
% recorded intervals MVPA (Activity Levels 4 and 5) | Inside:  
% recorded intervals LPA: 5%  
% recorded intervals MVPA: 1%  
Outside:  
% recorded intervals LPA: 27%  
% recorded intervals MVPA: 17% |
| **Pate et al**<sup>[245]</sup> | USA: 493 children, age: 3-5 years | The Observational System for Recording Physical Activity in Children-Preschool Version, ≥600 30-second observations | MVPA less than 3% of the observation intervals |
### Prevalence of physical activity in children aged 5 years or younger (continued).

<table>
<thead>
<tr>
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<tbody>
<tr>
<td><strong>Heart rate monitoring</strong></td>
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<tr>
<td>Jago et al[^366^]</td>
<td>USA: 142 children, mean age (SD)=4.4 (0.6) years</td>
<td>Quantum XL telemetry heart rate monitor (1-min epochs): 12 hrs/day, 4 days/year MVPA mins &gt;140 bpm/hr</td>
<td>4.2±3.6 MVPA mins/hr (corresponds to 7% of time)</td>
</tr>
<tr>
<td><strong>Proxy-report</strong></td>
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<tr>
<td>Australian Institute of Family Studies[^226^]</td>
<td>Australia: 5,104 infants (51% boys), age range 3-19 mths; 4,976 preschoolers (51% boys), age range 4.3-5.6 years</td>
<td>Proxy-report 24-hr time-use diaries over randomly selected weekday and weekend day Diaries covered an entire 24-hour period, except for any time the child’s activities were unobserved, such as when they were in child care or preschool For infants assessed (% who did; mean hrs/day): Crawl, climb, swing arms or legs Other play, organised activities For pre-schoolers assessed (% who did; mean hrs/day): Walking, riding a bicycle, or other exercise Other play, other activities</td>
<td>Infants (% who did; mean hrs/day): Crawl, climb etc. (70%; 2 hrs/day) Other play, organized activities (82%; 2.4 hrs/day) Preschoolers (% who did; mean hrs/day): Walking, riding a bicycle, or other exercise (66%; 1.2 hrs/day) Other play (69%; 1.8 hrs/day)</td>
</tr>
<tr>
<td>Ball et al[^220^]</td>
<td>Australia: 184 children (52% boys), age: 5-6 years</td>
<td>Proxy-report[^367^]. Information (type, frequency) on children’s participation in PA during a typical week (for weekdays and weekends), chosen from a list of common activities (considered to be MPA and VPA) relevant to the age group.</td>
<td>MPA: Boys: 24.1±12.1 times/week Girls: 27.7±14.4 times/week VPA: Boys: 11.1±7.4 times/week Girls: 9.2±6.2 times/week</td>
</tr>
<tr>
<td>Burdette et al[^213^]</td>
<td>USA: 214 children, mean age=3.7 years</td>
<td>Parental proxy-report: time spent playing outdoors: recall mins/weekday, mins/weekend day in last mth</td>
<td>Time spent playing outdoors: 146 mins/day</td>
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<tr>
<td>Author</td>
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<tr>
<td>Fitzgibbon et al[^157]</td>
<td>USA Latino preschools: 180 children (intervention) mean age (SD)=4.2 (0.6) yrs; 170 children (control) mean age (SD)=4.3 (0.6) years</td>
<td>Parental proxy-reported PA frequency to improve fitness (% ≥7×/week)</td>
<td>PA frequency (% ≥7×/week) intervention: 27% control: 22%</td>
</tr>
<tr>
<td>Kuepper-Nybelen et al[^218]</td>
<td>Germany: 1974 children (51% boys), age 5-6 years.</td>
<td>Parental proxy-report: doing sports or playing outside (&gt;1×/week)</td>
<td>92% play sports &gt;1×/wk</td>
</tr>
<tr>
<td>Manios[^368]</td>
<td>Greece: Age groups</td>
<td>Parental proxy-report child participation in outdoor organised and non-organised MVPA (&gt;4 METs) that results in heavy breathing and is longer than 20 mins duration</td>
<td>MVPA</td>
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<tr>
<td></td>
<td>1-2 years N=207 (48% boys)</td>
<td></td>
<td>Boys: 1.45±3.15 hrs/week</td>
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<td>2-3 years N=500 (55% boys)</td>
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<td>Girls: 1.05±2.29 hrs/week</td>
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<td>3-4 years N=922 (53% boys)</td>
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<td>2-3 years</td>
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<tr>
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<td>4-5 years N=745 (48% boys)</td>
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<td>Boys: 1.51±2.63 hrs/week</td>
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<td>Girls: 1.21±2.41 hrs/week</td>
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<td>3-4 years</td>
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<td>Boys: 1.27±2.52 hrs/week</td>
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<td>Girls: 1.09±2.09 hrs/week</td>
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<td>4-5 years</td>
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<td>Boys: 1.10±2.42 hrs/week</td>
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<td>Girls: 1.17±2.13 hrs/week</td>
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<tr>
<td>Okely et al[^222]</td>
<td>Australia: 266 children (140 boys). Mean age (SD)=3.96 (0.76) years</td>
<td>Physical Activity and Exercise Questionnaire for Children (PAEC-Q): Parental report on the time their child is with them, the number of hours their child spend in active play during a normal week day and weekend day</td>
<td>Active Play: Mean (SE) (hrs/day) Weekday: 3.2 (0.2) hrs/day Weekend: 4.1 (0.2) hrs/day</td>
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<tr>
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<td>Proportion of sample who met the NASPE Active Start Guidelines: ≥3 hr/day in active play</td>
<td>Mean (SE): 55.7 (4.1)% on weekdays, 79 (3.3) % on weekends met the NASPE guidelines</td>
</tr>
<tr>
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</table>
| Poest et al[369] | USA: 514 children (52% boys) attending preschool and daycare centres. Age not stated. | Modified National Children and Youth Fitness Study survey, parent and daycare/preschool teacher proxy-report time (hrs) child spends/week in gross motor activities | Boys: 26.43±12.2 hrs/week  
Girls: 24.14±11.8 hrs/week                                               |
| Sääkslahti et al[225] | Finland: 112 children (45% boys), mean age (SD)=4.4 (0.4) years               | Physical activity diary completed Spring and Autumn  
Combined measure by intensity (included indoors and outdoors):  
Low activity playing (hrs/wkend)  
High activity playing (hrs/wkend)  
Combined measure by location (included low and high intensity):  
Outdoor play (hrs/wkend) | Spring  
Low activity: 15.26±4.1 hrs/wkend  
High activity: 3.33±3.0 hrs/wkend  
Outdoor play: 4.0±3.2 hrs/wkend  
Autumn  
Low activity: 15.25±4.7 hrs/wkend  
High activity: 2.97±2.8 hrs/wkend  
Outdoor play: 6.27±3.3 hrs/wkend |
| Spence et al[221] | Canada: 501 children (48% boys), age 5 years.                                   | Parental proxy-reported hrs/week (over the last 2 wks) in structured PA and play % meeting Canadian PA recommendations – 90 mins/day – 10.5 hrs/week | Boys: 85%  
Girls: 77%                                                                  |
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<tr>
<td>Stolley <em>et al</em> [219]</td>
<td>USA: 416 black children (48% boys); 362 Latino children (51% boys), mean age=4.2 years</td>
<td>Parental proxy-reported physical activity</td>
<td>Exercised in last week (Black: 97.3%; Latino: 80.5%)</td>
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<tr>
<td></td>
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<td>Exercised in the last week (%)</td>
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<tr>
<td>Vandewater <em>et al</em> [223]</td>
<td>USA: Age groups: 0-2 years N=412; 3-4 years N=304; 5-6 years N=329 (sex proportions not reported)</td>
<td>Parental proxy-reported amount of time spent playing outside on previous day</td>
<td>Minutes played outside previous day (0-2 years=65.5±73.5; 3-4 years=96±85.3; 5-6 years=94.6±94.3)</td>
</tr>
</tbody>
</table>

N.B. *N based on available PA data.
APPENDIX B – Ethical Approval

Dr B Taylor
Department of Women's and Children's Health
Dunedin School of Medicine

8 April 2009

Dear Dr Taylor

I am again writing to you concerning your proposal entitled "Measuring the physical activity of children aged 3 to 7 years", Ethics Committee reference number 09/054.

Thank you for sending to me a letter addressing the concerns of the Committee. A copy of the letter of support from the child care centre was received, as well as notification of consultation with Māori, and updated Information Sheets.

On the basis of this response, I am pleased to confirm that the proposal now has full ethical approval to proceed.

Approval is for up to three years. If this project has not been completed within three years from the date of this letter, re-approval must be requested. If the nature, consent, location, procedures or personnel of your approved application change, please advise me in writing.

Yours sincerely,

Mr G K (Gary) Witte
Academic Committees, Academic Services
Tel: 479-0255
Email: gary.witte@stonebow.otago.ac.nz

c.c. Professor B J Taylor Head Department of Women's and Children's Health
Measuring the Physical Activity of Children aged 3 to 7 years

To the University of Otago Human Ethics Committee:

I have read and I understand the Information Sheet about this study, looking at measuring and recording a number of activities using a motion sensor and video cameras. I have had the opportunity to discuss this study and to ask questions which have been answered to my satisfaction.

- I understand that parent consent has to be given before the study and data collection take place.
- I understand that participation in this study will not cause the child more discomfort or risks than his/her daily activities.
- I have had time to consider whether to take part.
- I understand that I may withdraw locality approval if any significant local concerns arise. I agree to advise Manson Ku or Barry Taylor and then the relevant ethics committee should this occur.

I hereby, on behalf of the Kaikorai Primary School, approve Manson Ku and other researchers for this project to collect data at the school.

Signature: [Signature]  Date: 8/9/09.

Name: Nigel Wilson  Position: Principal

Contact details: (03) 464 0005

Kaikorai Primary School
APPENDIX C

Measuring the Physical Activity of Children aged 3 to 7 years

INFORMATION SHEET FOR PARENTS / GUARDIANS

Thank you for showing an interest in this project. Please read this information sheet carefully before deciding whether or not to participate. If you decide to participate we thank you. If you decide not to take part there will be no disadvantage to you or your child of any kind and we thank you for considering our request.

What is the Aim of the Project?
This study aims to use a motion sensor to measure and define sedentary behaviour, as part of our research to find a reliable method for measuring physical activity.

What Type of Participants are being sought?
We are looking for healthy children aged between 3 to 7 years to participate in the study, who are able to participate in physical activity. Children who have any major medical problems will not be able to participate in the project because, in the opinion of the researchers and the University of Otago Human Ethics Committee, it may involve an unacceptable risk to them.

What will Participants be Asked to Do?
Should you and your child agree to take part in this project, your child will be asked to wear a small motion sensor on his/her hip. He/she will then be asked to do various activities including watching TV, reading (or being read to), drawing, playing with puzzles or play dough for approximately 5-10 minutes per activity. We will ask your child to play video games such as Nintendo Wii Sport™ or Dance Dance Revolution™, or other similar games suitable for his/her age for 5-10 mins. If conditions permit, we may also study your child’s activities during free-play outside in the playground. If your child is attending the Hospital Early-Childhood Centre, his/her lunch time naps may also be measured. All activities will be recorded on video to allow closer observation of the movement involved during these activities.
It is expected that the total amount of time involved will be 1-2 hours. Collection of
data will mostly be carried out at the centre/school. We consider the activities
involved in the study to be familiar and enjoyable to your child and do not expect
them to involve any stress or harm. Your child can choose to not participate in
specific activities if they wish.

Can Participants Change their Mind and Withdraw from the Project?
You may withdraw from participation in the project at any time and without any
disadvantage to yourself of any kind.

What Data or Information will be Collected and What Use will be Made of it?
In addition to the video records and motion sensor measurements, we will also
measure your child’s height and weight and ask you to fill out a brief questionnaire
about you and your child. Please note that we will also ask for information about the
birth of your child.

    Measuring your child’s height and weight allow us to find out if body size play
a part in determining how we move or how much we move.

    When it comes to analyzing the data, only the student researcher (Manson) and
his supervisors (Barry, Rachel and Sheila) will have access to this information. After
the study is completed, the data collected will be securely stored securely for 5 years
as required by the University's research policy, after which it will be destroyed.

    The results of the project may be published and will be available in the
University of Otago Library, Dunedin and you are most welcome to request a copy
of the results of the project should you wish.

    It is our priority to ensure every attempt is made to preserve your and your
child’s anonymities.

What if Participants have any Questions?
If you have any questions about our project, either now or in the future, please feel
free to contact either:-
Manson Ku or
Professor Barry Taylor
Department of Paediatric
University Telephone Number:- 4747005

This study has been approved by the University of Otago Human Ethics Committee.
If you have any concerns about the ethical conduct of the research you may contact
the Committee through the Human Ethics Committee Administrator (ph 03 479
8256). Any issues you raise will be treated in confidence and investigated and you
will be informed of the outcome.
APPENDIX D

Measuring the Physical Activity of Children aged 3 to 7 years

CONSENT FORM FOR PARENTS/GUARDIANS

I have read and I understand the Information Sheet about this study, looking at measuring and recording a number of activities using a motion sensor and video cameras. I have had the opportunity to discuss this study and to ask questions which have been answered to my satisfaction.

- I understand that taking my child’s participation in this study is voluntary and that I may withdraw from this study at any time and this will in no way affect my or my child’s future health care.
- I understand that my child’s participation in this study is confidential and that no material which could identify me or my child will be used in any reports on this study.
- I understand that all the personal identifying information will be destroyed at the conclusion of the study and the rest of the data collected will be retained in secure storage for five years, after which these will be destroyed.
- I understand that my child’s participation in this study will not cause him/her more discomfort or risks than his/her daily activities.
- I understand that the results of the project may be published and will be available in the University of Otago Library, Dunedin, New Zealand but every attempt will be made to preserve my and my child’s anonymities.
- I have had time to consider whether to take part.
- I understand the compensation provisions for this study.

I agree for my child to take part in this project.

.............................................................................    ...............................  
(Signature of parent/guardian)      (Date)  
.............................................................................
(Name of child) 

This study has been approved by the University of Otago Human Ethics Committee. If you have any concerns about the ethical conduct of the research you may contact the Committee through the Human Ethics Committee Administrator (ph 03 479 8256). Any issues you raise will be treated in confidence and investigated and you will be informed of the outcome.
CONSENT FORM FOR CHILD PARTICIPANTS

I have been told about this study and understand what it is about. All my questions have been answered in a way that makes sense.

I know that:

1. Participation in this study is voluntary, which means that I do not have to take part if I don't want to and nothing will happen to me. I can also stop taking part at any time and don’t have to give a reason;

2. Anytime I want to stop, that’s okay.

3. Manson will video-tape me so that he can remember what I do, but the tape will be thrown away after the study has ended.

4. If I don't want to answer some of the questions, that's fine.

5. If I have any worries or if I have any other questions, then I can talk about these with Manson.

6. The paper and computer file with my answers will only be seen by Manson and the people he is working with. They will keep whatever I say private.

7. I will receive a small gift as thanks for helping with this study.

8. Manson and the people he is working with will write up the results from this study for their University work. The results may also be written up in journals and talked about at conferences. My name will not be on anything Manson writes up about this study.

I agree to take part in the study.

..........................................................................................................................  ................................
Signed        Date
APPENDIX E

PARTICIPANT EVALUATION FORM

Measuring the Physical Activity of Children aged 3 to 7 years

DEMOGRAPHICS:
- What is your child’s name?
- What is your child’s date of birth?
- What sex is your child?
  □ Female
  □ Male
- What is your child’s ethnicity? Please tick as many boxes as apply.
  □ New Zealand European / Other European
  □ Maori
  □ Samoan
  □ Cook Island Maori
  □ Tongan
  □ Niuean
  □ Chinese
  □ Indian
  □ Other (such as Japanese, Tokelauan)
    Please specify________________________

CONTACT DETAILS:
- Home Address: __________________________
- Phone: __________________________
- Mother’s Name: __________________________
- Father’s Name: __________________________

One other Contact person
- Name: __________________________
- Relationship: __________________________
- Address: __________________________
  __________________________
- Phone: __________________________
How would you describe your child’s overall health?

□ Poor □ Fair □ Good □ Very good □ Excellent

Does your child currently have any illness or disability which limits his/her activity and has lasted for more than three months?

□ No
□ Yes → Please specify ________________
____________________________
____________________________

BIRTH HISTORY:

□ What is your child’s gestation age at birth? ________________
□ What is his/her birth weight (g)? ________________
□ What is his/her birth length (cm)? ________________
□ What is his/her birth head circumference (cm)? ________________
□ Was there any problem at birth?
□ No
□ Yes → Please specify ________________
____________________________
____________________________

Is there any concern regarding growth/development so far?

□ No
□ Yes → Please specify ________________
____________________________
____________________________

MEASUREMENTS:

□ Weight:

□ Height:
APPENDIX F

ADVERTISEMENT PLACED AT THE EARLY CHILDHOOD CENTRE
AND PRIMARY SCHOOL

We need your help!

We are still looking for children aged between 3 to 7 years to take part in a study of measuring physical activities.

This study aims to work out how reliable a motion sensor is in measuring a number of activities in young children. The study could pave the way for an objective clinical tool to improve management of the increasing weighty issues in New Zealand.

During the study, we would ask your child to:
- wear a belt with the motion sensor attached
- partake in a number of activities such as reading, watching TV and playing video games

The study would take up to 2 hours.

This project is being conducted by the Paediatric Section, Department of Women’s and Children’s Health. It has been reviewed and approved by the University of Otago Ethics Committee.

If you are interested in taking part or have any questions – please do not hesitate to contact the researcher: Hsi-Yu (Manson) Ku on 4747005 or 0211609938
Email : kuhs3741@student.otago.ac.nz

Thank you for your time and consideration!
Measuring Physical Activity in Children Aged 3 to 7 Years

Dear Parents

I would like to invite you to join a new research study which is trying to work out how reliable a motion sensor is in measuring a number of activities in young children. We know that more and more children in New Zealand are becoming over-weight. Research has shown that sedentary behaviour (SB) is an independent risk factor associated with excessive weight gain and that targeting reduction in SB may be more effective in preventing development of overweight in children than targeting increases in physical activity. However this relationship requires to be clarified further and we need to know under what level of intensity of activity is SB. To study this we are recruiting a small group of young children. We want to video record 60 children aged 3 to 7 years wearing the motion sensor and doing some activities such as watching TV, playing video games and playing in a playground. This will help us to understand how sensitive the motion sensor is in detecting SB, how specific it is to distinguish SB from other more vigorous physical activities and what is SB in terms of the output unit of the motion sensor.

We have enclosed an Information Brochure outlining what is involved in taking part in this study. If you have any queries or would like to be involved please do not hesitate to contact Manson Ku my research student at 474-7005 ext 8154 or email him at kuhs3741@student.otago.ac.nz. We will make an appointment time to see you and your child either at the Dunedin Hospital Early Childhood Centre or Children’s Hospital Outpatients clinic, where we will start the activity monitoring as outlined in the enclosed information brochure.

This study has been approved by the University of Otago Ethics Committee.

Thank you for your time, and we look forward to hear from you.

Yours sincerely

Professor Barry Taylor
Paediatrician
Manson Ku is a final year medical student working under the supervision of Professor Barry Taylor, a paediatrician and Head of Department of Women’s & Children’s Health, University of Otago. They are members of a research team who are working on a study which could pave the way for an objective and reliable device for measuring sedentary behaviour (SB) and physical activity (PA).

Dear Parents:

I would like to invite you to join a new research study which is trying to work out how reliable a motion sensor is in measuring a number of activities in young children. We know that more and more children in New Zealand are becoming over-weight. Research has shown that sedentary behaviour (SB) is an independent risk factor associated with excessive weight gain and that targeting reduction in SB may be more effective in preventing development of overweight in children than targeting increases in physical activity. However this relationship requires to be clarified further and we need to know under what level of intensity of activity is SB. To study this we are recruiting a small group of young children. We want to video record 50 children aged 3 to 7 years wearing the motion sensor and doing some activities such as reading, watching TV and playing video games. This will help us to understand how sensitive the motion sensor is in detecting SB, how specific it is to distinguish SB from other more vigorous physical activities and what is SB in terms of the output unit of the motion sensor.

If you have any queries or would like to be involved please do not hesitate to contact Manson Ku my research student on 474-7005 or 0211609938 or email him at kuhs3741@student.otago.ac.nz. We will make an appointment to see you and your child at the Kaikorai Primary School, where the activity monitoring will be held.

This study has been approved by the University of Otago Ethics Committee.

Thank you for your time, and we look forward to hear from you.

Yours sincerely

[Signature]

Professor Barry Taylor
Paediatrician