Effects of the Environment on Physical Activity in New Zealand Children

LESLIE JULIAN MC GRATH

A THESIS SUBMITTED TO AUCKLAND UNIVERSITY OF TECHNOLOGY

IN FULFILMENT OF THE DEGREE OF

DOCTOR OF PHILOSOPHY

July 2013

SCHOOL OF SPORT & RECREATION

FACULTY OF HEALTH & ENVIRONMENTAL SCIENCES

PRIMARY SUPERVISOR: ERICA A. HINCKSON

SECONDARY SUPERVISOR: WILL G. HOPKINS

TABLE OF CONTENTS

ATTESTATION OF AUTHORSHIP

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of a university or other institution of higher learning, except where due acknowledgement is made.

Leslie Julian Mc Grath

Date: 26th July 2013

CO-AUTHORED WORK

Chapters 2-7 of this thesis represent six separate studies that have been submitted to peer-reviewed journals for consideration for publication. All co-authors have approved the inclusion of the joint work in this doctoral thesis.

Study 1

Title: Effect of the built environment on children's moderate-vigorous physical activity

Chapter 2 in thesis

Percentage contribution: 80% of work is my own, 15% is that of Professor Will Hopkins and 5% is that of Associate Professor Erica Hinckson.

Study 2

Title: Effects of neighborhood infrastructure on physical activity in New Zealand children

Chapter 3 in thesis

Percentage contribution: 80% of work is my own, 10% is that of Associate Professor Erica Hinckson and 10% is that of Professor Will Hopkins.

Study 3

Title: Children's step counts at light and moderate-vigorous intensities during school and non-school days

Chapter 4 in thesis

Percentage contribution: 80% of work is my own, 15% is that of Associate Professor Erica Hinckson and 5% is that of Professor Will Hopkins.

Study 4

Title: Power of Play: A Primary School Intervention to increase physical activity in New Zealand children

Chapter 5 in thesis

Percentage contribution: 80% of work is my own, 15% is that of Associate Professor Erica Hinckson and 5% is that of Professor Will Hopkins.

Study 5

Title: Examining loss of activity data in accelerometer studies with children

Chapter 6 in thesis

Percentage contribution: 85% of work is my own, 10% is that of Associate Professor Erica Hinckson and 5% is that of Professor Will Hopkins.

Study 6

Title: Accelerometer sampling interval and intensity thresholds effect on measures of children's physical activity

Chapter 7 in thesis

Percentage contribution: 80% of work is my own, 10% is that of Associate Professor Erica Hinckson and 10% is that of Professor Will Hopkins.

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGMENT

Knowledge is the most precious gift that one can receive so I truly thank Associate Professor Erica Hinckson and Professor Will Hopkins. I especially thank Erica for her trust, guidance and unyielding encouragement that I could complete this thesis. I owe a debt of gratitude to Will for sharing his wisdom and knowledge unreservedly. I thank you both for your humanity and understanding for assisting this not so talented and perhaps reluctant academic. Confucius said "To know that we know what we know and that we do not know what we do not know, that is true knowledge". I fear that the scales for me lean too far in favour of the "what I do not know" but I am certain that my knowledge basket is fuller because of Erica and Will.

After nearly three and half years of data collection, and a further year of data cleaning and analysis to do apologise to Will for my contribution to creating such a large data set for analysis. I unconditionally thank the URBAN study team lead by Professor Grant Schofield and Professor Karen Witten, Dr Hannah Badlands for managing the project and the contributions of the rest of the team Professor Robin Kearns, Professor Philip Schluter, Dr Melody Oliver, Suzanne Mavoa, Hector Kaiwai, Victoria Jensen, Christina Ergler, Julia McPhee and all the research assistants. I thank the Health Research Council (HRC) of New Zealand [grant number: 07/356] for the three years of scholarship, the Maurice & Phyllis Paykel Trust (Master of Health Science) scholarship, Health & Environmental Science (Masters Postgraduate Fee) scholarship, Health & Environmental Science (Doctoral Postgraduate Fee) scholarships, and others for their financial assistance. It is overwhelming and truly humbling that I could have received so much help. I hope that I may someday repay or at least pay forward the kindness. I also thank my fellow students Saeideh Aminian, Marcelo Castello, Olanrewaju Olotu, Caroline Dickson, Amy Curtis, Erika Ikeda, Leslie Woller, Rita Malcata, and Steve Hollings for the supportive chats. A special thanks to Professor Patria Hume, Professor Elaine Rush and Dr Scott Duncan for their support and encouragement. Thank you also to all those wonderful people at AUT that I have not mentioned by name.

Most importantly I thank my family, Kaori, Kosei and Ben for their unconditional love and support. To my mum a special thank you for your food parcels and petrol money when our pantry and petrol tank were empty. A special thank you also to my brother Alan cheers mate.

Collectively, my family have shared my grumblings without a whimper, smiled and made me laugh just when it all seemed too hard. I unreservedly thank my father- and mother-in-law Chikara and Yoko Takeji for their help and support kokorokara kansha siteimasu.（義父の竹治力氏と義母の竹治陽子氏の力添えと支援に、心から感謝と敬意を表します）Finally to my dear friends Dr Sean Ogden and his wife Anne for their help to see our house constructed where this thesis was written. Your unending trust and faith are remarkable and exceed the boundary of true friendship.

This thesis has received approval from the following ethics committees: Auckland University of Technology on 21st September 2007, AUTEC Reference number 07/126; on 16th April 2007, AUTEC Reference number 06/214; 25th February 2009, AUTEC Reference number 08/262; 2nd February 2009, AUTEC Reference number 08/261.

PUBLICATIONS AND CONFERENCE PRESENTATIONS FROM THIS PHD THESIS

ARTICLES SUBMITTED TO PEER-REVIEWED JOURNAL

Chapters 2-7 of this thesis represent individual papers that have been submitted to peer-reviewed journals for consideration for publication. These papers are listed below.

McGrath, L. J., Hopkins, W. G., & Hinckson, E. A. (2013). Effect of the built environment on children's moderate-vigorous physical activity. Manuscript submitted to Sports Medicine.

McGrath, L. J., Hinckson, E. A., & Hopkins, W. G. (2013). Effects of neighbourhood infrastructure on children's physical activity. Manuscript submitted to American Journal of Preventive Medicine.

McGrath, L. J., Hinckson, E. A., & Hopkins, W. G. (2013). Children's step counts at light and moderate-vigorous intensities during school and non-school days. Manuscript submitted to American Journal of Preventive Medicine.

McGrath, L. J., Hinckson, E. A., & Hopkins, W. G. (2013). Power of play: A primary school intervention to increase physical activity in New Zealand children. Manuscript submitted to 7th Annual International Conference on Kinesiology and Exercise Sciences Conference Proceedings; Athens Greece.

McGrath, L. J., Hinckson, E. A., & Hopkins, W. G. (2013). Examining loss of activity data in accelerometer studies with children. Manuscript submitted to Pediatrics International.

McGrath, L. J., Hinckson, E. A., & Hopkins, W. G. (2013). Accelerometer sampling interval and intensity thresholds effect on measures of children's physical activity. Manuscript submitted to Journal of Physical Activity & Health.

CONFERENCE PRESENTATIONS AND ASSOCIATED PUBLICATIONS

McGrath, L. J., Hinckson, E. A., & Hopkins, W.G. Classification of physical activity in children using accelerometers. Proceedings of ASICS conference of Science and Medicine in Sport; Hamilton Island, Australia: Sports Medicine Australia; 2008. p.14.

McGrath, L. J., Hinckson, E. A., & Hopkins, W.G. Physical activity in children: Capturing habitual intermittent activity accurately. Proceedings of ASICS conference of Science and Medicine in Sport; Brisbane, Australia: Journal of Science & Medicine in Sport, 12(6), 2009. p. 153.

McGrath, L. J., Hinckson, E. A., & Hopkins, W.G. Measuring Sedentary Behaviour in Children. Proceedings of Paediatric Society of New Zealand Conference: Starving in the age of wealth / recession: The ecology of child health; Hamilton, New Zealand; 2009. p. 83.

McGrath, L. J., Hinckson, E. A., & Hopkins, W.G. Sedentary Behaviour and Light Activity in Children. Poster: Sports Medicine and Science Conference; 2009; Rotorua, New Zealand.

McGrath, L. J., Hinckson, E. A., & Hopkins, W.G. Accelerometer Measurement Issues in a Primary School Play Intervention. Proceedings of 7th Annual International Conference on Kinesiology and Exercise Sciences; June-July 2011; Athens, Greece.

McGrath, L. J., Hinckson, E. A., Hopkins, W.G., & Mavoa, S. Local neighborhoods and moderate-vigorous physical activity in NZ children: The URBAN study. Proceedings of Annual Meeting of the International Society for Behavioral Nutrition and Physical Activity; May 2013; Ghent, Belgium.

ABSTRACT

Childhood obesity rates have risen steadily in recent decades along with increased urbanisation that has changed where children can play and roam freely, potentially reducing their daily energy expenditure. The relationship between aspects of the built environment and children's physical activity has therefore been identified as a public-health issue. This thesis represents a review, two studies that examined built-environment effects on children's activity, one play intervention study and two studies that investigated issues with accelerometer measurement of physical activity.

Chapter two addresses the need for a quantitative review of the effects of objectively measured built-environment factors on children's objectively measured physical activity. The review included studies that used geographical information systems (GIS) or street audits to quantify the built environment with physical activity quantified by accelerometers, pedometers or global positioning systems. A key insight was that danger from vehicle traffic appears to underlie the association between physical activity and some measures of the built environment. There was inadequate research on effects of neighbourhood walkability and on the confounding effects of weather, compliance and the intensity threshold for moderate-vigorous activity.

In Study 1, habitual physical activity of 227 children living in 48 residential neighbourhoods within four cities was measured with accelerometers and related to built-environment factors defined using GIS analysis and street-audit measures. Disparate built-environment effects on children’s physical activity were rationalised by classifying neighbourhoods as either safe for children’s walking or play or those where traffic danger constrained activity, which suggests that unsafe neighbourhoods need redesigning.

In Study 2 the same data were analysed with a particular focus on children's daily pattern of accelerometer steps at light and moderate-vigorous intensities. It was revealed that reductions in moderate-vigorous activity were associated with poor weather, darkness and non-school days. These reductions might be offset by interventions that encourage children to self-select outdoor or indoor activities at step cadences of ~80 per minute.

Modifying the built environment is a long-term health strategy towards developing child-walkable neighbourhoods where children can roam and play independently to increase their daily physical activity. A short-to-medium term intervention plan was implemented in Study 3, a crossover design for promoting children's increased physical activity through self-determined play during a supervised play period before school (08:00-09:00) with free access to play equipment. There were no clear changes in total activity, but during the play intervention there were trivial-small reductions in girls' body-mass index (BMI) while boys' BMI remained constant when normally BMI would be expected to increase. Reasons for excluding data from analysis in the intervention study were investigated in Study 4 and it was found that non-compliance and discomfort with wearing accelerometers along with monitor failure excluded half of the children from providing activity data for analyses. In the final study, the effect of accelerometer-count thresholds on the amount of activity classified as moderate-vigorous intensity was investigated and thresholds from published articles are recommended rather than manufacturer thresholds. In conclusion, future studies should investigate the effects of neighbourhoods designed to increase safety to encourage children's habitual activity. Measurement of physical activity should be undertaken by continuously wearing accelerometers (and global positioning system watches) and analysed using published count thresholds.

CHAPTER 1: INTRODUCTION

BACKGROUND

Childhood obesity and health

Internationally, there has been an epidemic increase in childhood obesity [8], which will decrease life expectancy and increase the global burden of disease in future adult populations [9-11]. Overall, 8% of New Zealand children were obese [12], but New Zealand Maori and Pacific Island children are respectively 1.5 and 2.5 times more likely to be obese [13]. Obesity rates in Canadian primary school children have doubled since the 1980s [14] and the incidence of obesity among Australia youth is accelerating [15] prompting calls for childhood-obesity prevention programs [16]. Obesity generally tracks from childhood into adulthood [17-18] so intervening early is required because physical inactivity, high blood pressure, high blood glucose, overweight and obesity are responsible for a third of global mortality in adults [19].

Kylin, a Swedish physician in the 1920s chronicled several metabolic disturbances, including hypertension, hyperglycaemia and gout as being associated with cardiovascular disease [20]. In 1939, Himsworth and Kerr [21-24] reported that insulin insensitive diabetics tend to be obese, have high blood pressure, show signs of atherosclerosis and tolerate high dosages of insulin without developing hypoglycaemia. Upper-body adiposity was also found to be associated with metabolic abnormalities, Type 2 diabetes and cardiovascular disease [25]. In 1958, abnormal lipid metabolism, hypercholesterolemia and hypertriglyceridemia were linked to cardiovascular disease and diabetes [26-27].

Clustering of cardiovascular disease and diabetes risk-factors in an individual is known as metabolic syndrome. In children metabolic syndrome is defined as the presence of three or more risk factors; obesity, abnormal glucose regulation, diabetes, hypertension, dyslipidemia and low levels of high-density lipoprotein cholesterol [28]. Metabolic syndrome was present in 20% of obese children and individual risk-factor rates were dyslipidemia 42%, insulin resistance 29%, hyperinsulinemia 20%, glucose intolerance 19%, hypertension 15% and Type 2 diabetes 2% [28]. Children with Type 1 diabetes are also more likely to be obese [29-30], and obesity is associated with elevated levels of remnant lipoprotein cholesterol, which is an indicator of vascular dysfunction and a precursor to atherosclerosis [29, 31-32]. Other predecessors of cardiovascular disease, elevated levels of low-density lipoprotein cholesterol and low levels of high-density lipoprotein cholesterol [33-34] have been detected in children (6%) and remained a health risk for 40% of those children in adulthood [35]. Single health-risk factors relate weakly to low levels of physical activity in children, but clustering of four risk factors, which afflicts 10.6% of children, is strongly associated with lower levels of physical activity [36]. Clustering of risk factors is reported to track into young adulthood potentially developing into diabetes and cardiovascular disease [17].

Other health-risk factors arise during childhood owing to poor diet and low levels of physical activity [37-38]. Asthma is reported at seven times the normal frequency in overweight or obese girls [39] and overweight children develop low grade systemic inflammations at three times the rate of normal-weight peers [40]. In addition, disordered breathing during sleep was more prevalent in obese children (26%) than normal-weight children (2.3%) [41]. Osteoporosis normally afflicts older adults, but is increasingly considered a pediatric issue [42] because less physically active children have lower bone-mineral accrual than more active children [43].

Obesity related psycho-social disorders

There is an increased incidence of psychiatric or psychological disorders among overweight or obese children including depressive symptoms in preadolescent girls [44] and low self-esteem [45] though these symptoms are not always found [46]. The psychosocial impact of childhood obesity also manifests as self dissatisfaction with appearance [47-48].

Studies of the prevalence of depression in overweight and obese children reveal that these individuals are no more likely to have symptoms of depression than normal-weight children [49-50]. Obese boys report slightly higher levels of depression than normal-weight boys [51], but elevated body-mass index is not a predictor of depression in girls [52]. Nevertheless, depression during childhood has been identified as a risk factor in the development of adult obesity [53].

Higher body-mass index is often associated with decreased self esteem in children [45, 54]. Although mean self-esteem scores are low, these scores tend to generally fall within the normal range for obese and overweight children [55]. Low self-esteem invariably results from stigmatisation of obese children by other children, which increased by 40% in 2001 compared with results from forty years earlier [56]. Weight teasing is a risk factor in low self-esteem causing damage to emotional wellbeing that lasts into young adulthood [57].

Body dissatisfaction research using figure arrays [58-59] reveal that children, especially girls, choose ideal figures thinner than their current body size [60] and that normal body-sizes are acceptable whereas very thin or fat bodies are undesirable [61]. Overweight children and in particular overweight girls report greater body dissatisfaction than normal-weight children [62-65]. However, the association of body-mass index and psychological distress is only associative as body image varies considerably with some overweight individuals viewing their physique positively, while others are distraught [66].

Childhood obesity is a strong predictor of adult obesity [18], which predisposes these individuals to greater health complications in later life [67]. The early onset of diabetes, asthma, metabolic syndrome and psychological disorders associated with childhood obesity are good reasons for reducing overweight conditions in children [68-69].

Reduced energy expenditure or increased energy intake?

It is unclear whether the rise in obesity and overweight conditions is due to increased energy intake or reduced energy expenditure [70]. Some literature reports increased energy consumption evidenced by 15% more total food energy available in the market place [71]. Other literature supports the notion that there has been negligible change in overall energy intake and that energy intake is not related to body fatness [72-74]. After adjustments are made for energy expenditure, the energy intake of obese children is less than the energy intake of normal-weight peers [75]. Reduced growth-hormone response to exercise in obese children [76] leads to decreased fat utilisation during exercise [77] that actually preserves body fat. These findings support the theory of a reduction in energy expenditure as the main determinant in the obesity epidemic [78] but a definitive answer to the cause of obesity may be obscured. Evolution may play a role, which has selected for physiological mechanisms that defend against body-weight loss during famine while other mechanisms have evolved that promote weight gain when food is in abundance [5].

An obvious strategy against obesity is to reduce children's food consumption. This approach is problematic as imposing restrictions on what children eat is reported to be associated with increased food intake [79]. It is unclear if parents are restricting their child's diet in response to a child being overweight or whether dieting is a causative factor in higher body-mass index [80]. Poor parental food selections and force feeding may contribute to children's increased body-mass index by overriding children's natural cues for hunger and satisfaction [81]. However, condemning fast food and emphasizing overweight risks may also have negative effects on children's eating behaviours and body-mass index suggesting that different approaches are required [82].

Increasing physical activity a potential solution

Many health professionals advocate promotion of physical activity for children and adolescents as a preventative measure against adult obesity [8]. This rationale is based on evidence that adults that pursue an active lifestyle have lower risks of all-cause mortality, cardiovascular disease, some cancers, diabetes, depression and reduced prevalence of obesity and osteoporosis [83]. In contrast, the population attributable risks of physical inactivity for mortality are high for coronary heart disease (35%), diabetes mellitus (35%) and colon cancer (32%) [11]. Respectively, mortality from these diseases would be theoretically reduced by the said percentages if everyone was sufficiently active in daily life [11]. Nonetheless, the proportion of physically active adolescents declines from 13-19 y [84], which is consistent with previous findings that physically active youths may not subsequently become active adults [85-86].

Most physical activity guidelines suggest that children need at least 60 minutes (and up to several hours) of moderate to vigorous physical activity [8] and should not spend more than two hours daily using electronic media for entertainment [87]. A recent New Zealand study found that no children met the 60-min moderate-vigorous guideline [88], whereas in other studies 30-100% of children met activity guidelines [89-90]. These findings suggest that for many children the education and health systems are failing to inspire children to lead an “active lifestyle”.

Barriers to physical activity

Negative sport and exercise experiences, societal restriction of females, safety issues, too much time spent in sedentary pursuits, lack of play space, reduced time spent with friends, poor parental example and lack of encouragement disengage children from physical activity [91]. Children’s willingness to engage in physical activity depends upon the degree of perceived barriers [92] and their perceived physical competence [93]. The physical education curriculum may be disengaging students from being physically active because most of the lessons are sport-based activity [94-95]. Children with low-skill level in sports are unable to participate fully, which may reinforce feelings of inadequacy and further undermine their self esteem and self confidence [92-93]. Children want organised play time, more variety and exciting options with more female orientated activities for girls [96]. Consequently, the physical education and health curriculum needs to also promote routine play, active transport, recreation, and non-sport games as a means of increasing physical activity.

Sedentary behaviours

When the home environment is less conducive for children’s physical activity the alternative is sedentary activities. Excessive television viewing and having a television in a child's bedroom are associated with increased overweight risk among children from low income families [97]. Furthermore, childhood body-mass index is directly proportional to the mean hours of television viewing [98]. A longitudinal birth-cohort study undertaken in New Zealand reported that 17% of overweight and 15% of poor fitness in adults can be attributed to watching television for more than 2 hours per day during childhood and adolescence [99]. Each hour of time children spent playing electronic games was associated with a nearly two-fold increase in the risk of obesity [100]. Girls that play more video games have higher body-mass index whereas computer usage for non-game purposes was higher in lower-weight children and not associated with higher-weight status [101]. Overall children with higher body-mass index spend more time in sedentary pursuits than their normal-weight peers [101]. It has been suggested that a threshold of three hours of sedentary behaviour is a predictor of children's lower physical activity levels [102]. Reducing sedentary behaviour and other obesity prevention strategies are best instigated during childhood as this is a period when active routines and dietary habits are formed [103-104].

Parental influence

Parents are important role models so it is no surprise that children are more likely to be overweight or inactive when their parents are obese and more sedentary [105-106]. Parents may also discourage children from playing outside and interacting with friends when the neighbourhood environment is unsafe, which have a negative effect on children’s habitual physical activity [107-108]. Of equal concern is the fact that some researchers caution that the child's world of play has become over regulated, privatised and supervised by adults [109]. This may indeed be denying children the fundamental development opportunities, to self-determine play and physical activity, thereby restricting the formation of beneficial habits, behaviours and attitudes towards physical pursuits.

Time spent with friends, positive parental exercise attitudes and habits, encouragement and time spent being physically active with children engage children in physical activity [91]. In fact, highly active children were more likely to have parents that regularly spent time being physically active with them [110]. Time spent playing outside also increased children's daily physical activity [111]. Higher levels of activity indicate better self perceptions of physical confidence, which is associated with increased physical activity during non-school hours [111]. To complement this, active children have parents who restrict sedentary behaviours and encourage physically active alternatives [112].

Transportation choices

The use of transport for daily travel to and from school in Auckland, New Zealand is dominated by the private car (55%) and public transport (6%) with only 39% of children using active transport options of cycling or walking [113-114]. Over recent decades the annual total kilometres travelled and time children spent in cars has more than doubled, which is attributable to longer and more frequent vehicle journeys [115]. It has been reported that more than one third of Auckland children spend less than five minutes walking daily as a commuter [116]. This contradicts health professional recommendations and is the result of parental concerns about children's competence crossing roads, traffic volumes and social norms [117]. Ironically, chauffeuring children to school denies children the opportunity to develop traffic-safety awareness, increases traffic volumes and exposes other children to greater traffic-danger [118]. Socioeconomic disadvantage reduces the feasibility of chauffeuring, creating ethnic disparity for many Maori and Pacific Island children who are consequentially exposed to higher levels of traffic danger, injury and death [119-120]. It is recommended that traffic-calming measures are used in vulnerable districts as it has been found to reduce child-pedestrian injury rates [121-122].

Children exposed to more traffic around their home from age 10 to 18 y were more likely to have higher body-mass index than those exposed to lower traffic-volumes [123].

Initiatives that promote safe active-transport, develop the habit of independent travel and encourage less car journeys are important for children's health [124]. The Walking School Bus is a step in the right direction because it provides children with the opportunity to walk, which was reported as children's (72%) preferred mode of transport [118]. Walking school-buses operate over an average distance of 1.2km potentially providing up to 30 minutes of moderate physical activity per day. Recruiting and organising parent volunteers to act as conductors on walking school bus routes is the greatest challenge to the success of this initiative [125].

Should the focus be on the local environment?

Comparisons of current and historical childhood play behaviours indicate that independent outdoor play has been gradually replaced with more adult organised activities; music lessons, sport, family time and leisure pursuits like the cinema or museum [126]. In addition, children's photos and maps depict sedentary entertainment televisions, computers and electronic games as often as outdoor play and activity in local parks, sports fields and backyards [127]. Factors that restrict outdoor play include parental anxieties about children's safety, the changing nature of play, and the provision of inadequate play facilities [128-129] that are only fun with playmates [126]. High-density housing complexes that provide many playmates often result in lower levels of daily activity because children remain segregated owing to parental restriction, confined living and lack of play space [107].

Adults comprehend the local environment as innately hazardous in contrast children view the world as one large playground. Children will play in parks, playgrounds and backyards or in any nearby setting whether it be a street, alleyway, vacant lot, industrial estate, shopping centre, wasteland, creek, swamp or woodland [124, 130]. Childhood play and interactions with the local environmental are unremarkable to adult eyes yet these experiences shape personal identity, develop motor skills, cognitive abilities, social adeptness and a sense of belonging to a neighbourhood [129, 131]. Children that play in public spaces also serve a greater societal role by acting as a bridging agency between other children and people of diverse backgrounds that contributes to community cohesion [126].

A New Zealand study reported the proportion of children's freedom to travel alone to neighbourhood destinations rose from 50% at age 9 to 80% by age 11, which was mediated by traffic flow and fear of assault, bullying or molestation [124]. Children in the study reported that loss of freedom was often compensated for by chauffeured visits to recreational facilities or permission to play on quiet streets in front of the house [124]. The most common neighbourhood destination that children visited excluding school, was the shops, spontaneous walks, playgrounds and a friend's houses [132]. Interestingly, the authors also reported that children who walked often perceived neighbourhood roads as dangerous, which may in part be due to awareness of parental concerns and the need to be vigilant [132].

Children's declining participation in active transport, outdoor play, physical education and organised sports have increased a preference for television watching, eating and sleeping [133]. These changes in activity behaviour are attributed to school policy, parental restriction and environmental factors [133]. The need for interventions to reverse the trend towards inactivity is clear. Past interventions by health professionals to increase children's physical activity have produced modest results [134]. Providing play equipment at school increased daily moderate-vigorous activity in both active and inactive children [135]. Children want permission to play and organised playtime [136] in a safe, convenient environment [137] that permits unstructured play with interaction between peers so that children can accumulate regular health benefiting exercise [102].

Previous studies have quantified total daily physical activity and apportioned physical activity accordingly to school, non-school, weekday and weekend segments of time and physical education, recess and lunch [138-142]. A review of the effects of neighbourhood environment on children's habitual physical activity found that objectively measured environmental attributes were associated with self-reported but not objectively measured activity [143]. Also important is the issue of maturation [144], which alters children's physical activity behaviours, their play and mobility within the local environment [124].

When and where to intervene?

Declines in physical activity occur between the ages of 5-7 y and at the beginning of puberty, which are critical periods for the onset of obesity in children [145]. Population-based interventions that encourage children to be more active is a precautionary strategy as preventing weight gain is easier, less expensive and more effective than treating obesity once it has developed [1-3]. Parental participation in children's interventions are encouraged because long-term outcomes are improved by parental encouragement [146]. Interventions designed to increase physical activity should be culturally sensitive, school based, focused on early childhood, theory based and have physical activity sessions available within and outside school hours [147]. If physical activity and learning to live an active lifestyle are the goal then the environment that children are exposed to needs to provide multiple opportunities for physical activity as part of normal daily living [148]. The physical activity environment is best transformed when multilevel interventions are utilised, which are more effective than single level approaches [149].

What do we know about interventions?

Many past interventions have produced modest results [134]. Interventions at the individual level alter behaviour initially but tend to fail in the long term [150] as participants relapse back into sedentary behaviours after the intervention is complete [151]. Even well funded, intensive and extensive longitudinal interventions produce negligible outcomes [152]. Diet-based interventions produce improvement during the intervention but post intervention results are not much better than the baseline [153]. This implies that interventions need to improve exercise behaviours and be a permanent aspect of daily routines.

School-based interventions

The concept of the walking school-bus or chaperoning children on their walk to school was first proposed two decades ago [154]. The first walking school buses were established in Canada as part of the Active and Safe Routes to School project and rapidly expanded into the United Kingdom, New Zealand, Denmark, and the United States [113, 155] with walk to school promotions in more than 40 countries. Children that walk or bicycle to school have higher daily levels of physical activity and better cardiovascular fitness than those that do not actively commute [156]. Three walking school-bus routes in a Seattle elementary school increased the percentage of children walking to school from 19% to 26% over a 6 month period [157]. Similarly, the development of school travel plans and encouragement towards eco friendly travel increased the percentage of children walking to Auckland primary schools from 40.5% to 42.2% over five years [113]. Conversely, the impact of school travel planners in London primary schools provided no significant change in the already high percentage (70%) of children walking to school [158]. Half of walking school bus routes in Christchurch stopped after 18 months suggesting that further planning was required to ensure the sustainability of walking school buses [159].

School recess interventions

Recess at school offers a unique opportunity for unstructured play where children can self-determine physical activity through interactions with their peers to accumulate recommended daily physical activity [102]. Play periods are mandatory, occurring two times a day, five days a week for 39 weeks of the year in a safe well structured environment[137]. Just 40% of playtime spent in moderate-vigorous activity can provide approximately 30 minutes of daily recommended activity per day [160].

Introducing play equipment to play periods increased the time (pre 48%, post 61%) both active and inactive Belgium children spent in moderate-vigorous physical activity during play breaks [135]. Enriching the playground environment with soccer goals, basketball hoops and colour-coded play-areas combined with more daily play time resulted in trivial increases in children's moderate-vigorous activity [161].

Educational and promotional interventions

Classroom lessons have been used to disseminate nutrition, physical activity, and sedentary behaviour advice, promote active transport and deliver family education packages. Overall these educational approaches have negligible to small positive effects on physical activity, fitness, serum cholesterol and body-mass index.

The Kahnawake Schools Diabetes Prevention Programme included multiple interventions over a three year period with positive effects on physical activity, fitness and television viewing [162] but after eight years the long-term effects were negligible [163]. Three years of the "Know Your Body" intervention produced negligible effects on body-mass index and skinfold measurement, fitness scores remained constant but high-density lipoprotein cholesterol increased favourably [164]. The Israel version of "Know

Your Body" (SEGEV) also positively influenced cholesterol levels concurrent with a reduction in body-mass index after two years of intervention [165]. The Kiel Obesity Prevention Program a combined school and family-based intervention had positive effects on the proportion of children engaging in physical activity (58% to 65%) and decreased their skinfold measurements and body fat percentage [166]. The 'Be Smart' intervention used lunchtime clubs to promote nutritional and physical activity behaviours with no significant intervention effect on either physical activity or nutrient intake [134].

Reducing sedentary behaviours

A randomised controlled trial aimed at reducing sedentary behaviours by self monitoring and budgeting television viewing, video tape and video game usage decreased children's body-mass index [103]. An eighteen lesson curriculum-based intervention to reduce television, videotape and video game usage had positive effects on body-mass index, skinfold measurements and waist circumference although there was no change in children's physical activity levels and fitness [167]. The Eat Well and Keep Moving program implemented over two years reduced dietary fat (-1.1% P = 0.02) and television viewing (-0.55 hr/day), but there was no change in vigorous physical activity levels [168].

Multifaceted interventions

A combined family and curriculum-based health promotion of physical education classes and healthy school lunches improved children's fitness and high-density lipoprotein cholesterol [169]. Ten weeks of daily aerobic classes combined with incentives and educational knowledge to help children make good nutrition choices decreased obese children's body mass [170]. The Pathways family program promoted dietary change and increased physical activity [171] but did not reduce children's percent body fat or overall energy intake [172], however children from intervention schools were more active [173]. The Dance for Health intervention replaced physical education classes with health education and dance classes that resulted in a reduction in body-mass index ($P < 0.05$), resting heart rate ($P< 0.01$) and improved children's one mile run times [174]. Another study that used web-based lifestyle and nutrition advice and aerobic classes had a positive effect on cholesterol levels but no significant change in body-mass index, VO_{2max}, or skinfold measurements [2]. The Bienestar Health Program promoted reduced fat intake, increased physical activity and dietary fibre to control diabetes, which decreased children's fasting glucose levels [175].

Mandatory physical education classes and nutrition advice were used in 16 studies to increase daily physical activity but there were only non-significant increases in physical activity [176-179] or fitness [2, 175] but dietary fat intake was reduced [179-181]. After three months of mandatory physical education classes fitness and blood pressure were unchanged yet at eight months children's blood pressure decreased and VO_{2max} (3.7ml/kg/min, 95% CI; 2.2-5.3) increased [182]. Therefore longer duration interventions are required to accrue fitness and cardiovascular health benefits [182]. Six months of nutrition advice for children and parents, additional physical education classes and sports equipment for use during recess decreased boys body-mass index and improved children's cardiovascular fitness [183]. Modifying physical education classes to increase children's aerobic activity improved children's VO_{2max} and decreased their skinfold measurement and blood pressure [184]. The addition of three 30 minute physical education classes per week added six min additional daily moderate-vigorous physical activity but had no effect on physical activity outside of school [185]. Another study instigated daily physical education classes, provided play equipment and made low-fat foods available, which did not change dietary fat intake but increased children's activity levels and reduced boys body-mass index [178].

Pure promotional and educational interventions aimed at increasing dietary fibre, fruit and vegetable intake, and reducing dietary fat while improving physical activity knowledge were ineffective at reducing body-mass index, skinfold measurements or percent body fat. Of the pure promotional and education interventions only three positively influenced physical activity levels [113, 157, 166]. Only interventions that had mandated physical activity or physical education classes had the ability to increase both children's fitness and activity levels.

Assessing energy expenditure and physical activity

Children's spontaneous and intermittent physical activity patterns are difficult to measure accurately owing to the variety of activities that children participate in and the differences in the intensity, frequency, and duration of the activities [186]. Based on the definition of physical activity as any bodily movement produced by skeletal muscles that results in energy expenditure, using direct or indirect calorimetry to estimate energy expenditure appears ideal [187] but calorimetry is impractical for measuring children's habitual physical activity [188]. Doubly labelled water is accurate and safe for measuring total energy expenditure but is costly and cannot detect patterns of physical activity [187]. Other methods have been used to measure children's physical activity including self reports (recall questionnaires, interviews, diaries, proxy-reports), heart rate monitoring, direct observation, and motion sensors (pedometers, accelerometers) [144].

Self-reports are low cost and commonly used in large population studies, however self-assessed physical activity questionnaires are not recommended for children owing to recall bias, and inaccurate reporting of the duration and the intensity of physical activities [187]. Heart rate monitors provide a record of heart rate that is linearly related to energy expenditure but physical activity is overestimated (30%) when the heart rate is elevated due to other factors e.g. emotional stress, dehydration or illness [189].

Direct observation can provide information about the type of activity, the setting and the related social interactions but is rarely used to quantify energy expenditure in children. The Children's Activity Rating Scale is typically used in direct observation to classify physical activity into five categories, stationary and motionless, stationary with limbs or trunk moving, translocation easy, translocation moderate to strenuous [190]. Analysing observations is inherently difficult and only possible with video analysis using an observation period of 1-3 s to capture the transitions between activities [191].

Pedometers generally count steps accurately but over estimate distances travelled, and are even less accurate for estimating energy expenditure [192]. However, pedometers are low cost, small and very effective as a self monitoring device capable of providing motivational feedback to increase physical activity among youth [193].

Accelerometers are lightweight, compact in size, unobtrusive to wear and provide acceptable estimates of energy expenditure in laboratory conditions [194]. However, participant's energy expenditure may be underestimated with accelerometry during some activities e.g. vacuuming, dusting, or fast walking while energy expenditure during other activities e.g. window cleaning or slow walking are overestimated [195].

Objective monitoring using accelerometers and pedometers with activity expressed as step counts, accelerometer counts or time spent at a given intensity is generally preferred when studying children's complex patterns of physical activity and sedentary behaviours [196]. There are issues with measuring children's physical activity using motion sensors including thresholds to define activity intensity, epoch or sampling interval duration, monitor worn time and compliance [197-199].

Theoretical models of physical activity

The ecological model of four domains (recreation, transport, occupation, and household) of active living shown in Figure 1.1 proposes that policy decisions and the physical environment influence habitual activity [4]. There are multiple influences on physical activity that are incorporated into the active living model including: the policy environment (existing laws, rules, regulations, codes); the physical environment (weather, topography, urban design, natural features); interpersonal attributes (culture, social support, personal safety, crime); and intrapersonal traits (demographics, family situation, psychological, biological) [4]. Perceptions of the settings where activity can take place and policy environments are likely to influence physical activity behaviours [4]. Ecological models of physical activity advocate that provision of safe, attractive, and convenient places for physical activity and encouragement to use those places are important to increase habitual activity [200]. Additional research is required to understand relationships between physical activity, community design, transportation systems, and recreation facilities [4]. Although more research is required to understand the multiple influences on physical activity behaviour in specific urban settings [7] studies in this thesis will focus on the effect of objectively-measured characteristics of residential neighbourhoods on children's physical activity.

This image has been removed by the author of this thesis for copyright reasons.

Figure 1.1. Ecological model of four domains of active living [4].

Theoretical determinants of children's physical activity

Redesigning communities and neighbourhoods is a long-term approach to increase habitual activity. Other more immediate intervention strategies are required to increase children's daily physical activity. Intervention approaches should be based on theories that explain and predict children's participation in physical activity [201]. The theory of planned behaviour suggests that participating in physical activity depends on the child's intention or motivation and this is determined by their perception of behavioural control, the ability or competence to perform the activity [202]. Social Cognitive Theory proposes that additional factors predict children's physical activity participation including social support, self-efficacy or competency, self-regulation (setting goals and planning to be active) and outcome expectations of fun and enjoyment [203].

Social Cognitive Theory and the Theory of Planned Behaviour are models of behaviour in which personal, behavioural and environmental factors interact reciprocally to predict the outcome behaviour [202-203]. The Power of Play intervention in the present thesis was based on Social Cognitive Theory [203] and the Theory of Planned Behaviour [202]. The play intervention provided social support in a safe, enriched and unstructured play-environment at school that increased opportunities for children to self-determine play. Provision of oversized as well as normal sized play equipment during before school play periods and recess created the opportunity for children to develop increased physical competency. Improved self-efficacy at play serves to increase expectations for success, fun and enjoyment regardless of the child's initial competency or skill. A goal of the Power of Play is that children develop positive attitudes towards physical activity so that they acquire the habit of planning to be active.

Conclusion

Preventing weight gain is more effective than treating obesity once it has developed [1-3] yet interventions to increase physical activity and improve nutrition have produced negligible to small effects and have been mostly ineffective at reducing body-mass index. The environment of today is dramatically different from 20 years ago and is postulated to contribute greatly to the obesity pandemic [5]. Yet research to date has not clearly identified which changes to the environment account for lower physical activity that contributes to childhood obesity. The neighbourhood environment has the potential to affect the long-term health of most children by increasing the daily physical activity they experience through play and active commuting [6-7]. Understanding which environmental variables contribute to children's routine physical activity will provide evidence of what to modify in the environment to increase children's activity. Alterations to the built environment take years to be implemented so short-medium term approaches to increase children's habitual activity are required. The purpose of the studies in this thesis is to identify some of the environmental variables that contribute to differences in New Zealand children's habitual physical activity. In addition, other studies in the thesis will examine accelerometer measurement issues including compliance, thresholds, sampling intervals and the effects of a play intervention on physical activity.

THESIS RATIONALE

In recent decades, children's eating and exercise habits have changed resulting in positive energy-balance, an increase in obesity and physical inactivity [8, 204]. Dietary advice interventions have had limited success at reducing children's body-mass index [2, 172, 175, 178, 180-181]. Changes to the built environment have decreased time children spend playing and being physically active outdoors [126-127]. Outdoor play in urban environments is constrained by parental anxiety about children's safety from vehicular traffic, assault, bullying or molestation [124, 128]. Constraining children's play and independent mobility has encouraged children to prefer sedentary indoor activities like electronic games and television watching to the detriment of active pursuits [133]. Children with permission to play and explore the local environment seize the opportunity to be physically active [130]. The local environments that are suitable for children to roam and play in freely have not been well defined in research. Understanding the barriers and facilitators to children's neighbourhood roaming and play will inform city designs that encourage children's physical activity thereby providing an intervention that is enduring.

Changing the built environment is a long term strategy to increase children's habitual activity. Interventions that can be implemented immediately are required to promote children's daily physical activity. School has been identified as an environment that contributes to recommended daily levels of moderate-vigorous activity and much of the activity is performed at play during recess [205]. Interventions that provide play equipment, enrich the playground environment and provide increased opportunity for play have had some success at increasing children's habitual activity [135, 161]. In this thesis the Power of Play project incorporated the intervention strategies of previous studies [135, 161] and provided children access to play and sport equipment during class breaks and before school play periods.

The Understanding of the Relationship between Activity and Neighbourhoods (URBAN) study was designed to determine associations between Geographical Information System (GIS) measures of residential areas and physical activity in adults and children [206]. Data from four New Zealand cities were collected as part of an international study in eight countries using the International Physical activity and Environment Network (IPEN) protocols to examine associations between adult and children’s physical activity and the built environment.

Chapters three and four in this thesis examine children’s activity data along with GIS and other neighbourhood data collected in the URBAN study to determine some of the environmental factors that influence children’s habitual physical activity. In chapter five of the theses the effect of play equipment and extra opportunities for play is examined as a short-medium term strategy to increase children’s habitual activity. Accelerometer measurement issues of data loss and thresholds are examined in chapters six and seven respectively.

Thesis aims

Aim 1: To provide an overview of the literature on childhood obesity and physical activity to identify potential research questions and strategies to increase children’s habitual activity.

Aim 2: To review studies linking aspects of the built environment with children's moderate-vigorous physical activity.

Aim 3: To determine the strength of associations between GIS measures of the residential neighbourhood and children’s physical activity.

Aim 4: To determine the effect of meteorological variables on children’s steps accumulated at light and moderate-to-vigorous intensity.

Aim 5: To implement an intervention to increase children’s physical activity by providing play and sport equipment for children to engage in self-directed play before school and during class breaks.

Aim 6: To examine reasons for children's non-compliance and other factors that affect data loss in accelerometer studies.

Aim 7: To compare children's physical activity using different thresholds and sampling intervals.

Thesis background

This thesis incorporates the Power of Play project, which was transferred to the Doctoral program and findings from the URBAN study. The studies in this thesis combine findings from the two projects which together form a comprehensive analysis of children's physical activity in the school and non-school environment. The six month intervention study was implemented in two schools and supervision of the before school and recess play periods provided a unique opportunity to observe children's patterns of physical activity. Data from the play study revealed that some highly active children during school hours were the least active at home and findings from the URBAN study are an in-depth analysis of the effects of the residential environment on children's habitual activity.

My role in the URBAN study was to prepare all the accelerometers, download all the adults and children's accelerometer data, transcribe the travel diary's of all participants, perform all the street audits and collate, match and prepare all of the data for analysis (excluding the URBAN survey data). Data collection for the URBAN study was projected to take 18 months but the actual time taken was 30 months. Complete analysis of all URBAN study data took a further 18 months and was performed by Professor Hopkins with assistance from Associate Professor Hinckson and myself. Other analyses of data collected during the thesis including parent's perceptions of the built environment and the validity of the Actical step-count function were precluded.

Choice of participants

Overall, physical inactivity is estimated to cause 1.9 million deaths globally from cancer, diabetes and heart disease accounting for 30% of annual deaths and 43% of the global burden of disease [207]. Although it is difficult to define an exact threshold of activity that is beneficial for health, most activity guidelines recommend that children engage in 60 min of moderate-vigorous activity daily [8, 208]. Many young people do not engage in recommended levels of physical activity and half of children and adolescents were not sufficiently active for their health [8, 209]. Childhood is an important period when physically active routines and habits are formed [103-104]. For these reasons, the thesis projects are focused on primary and intermediate school children.

Choice of measures

Measuring physical activity

Robert Boyle and John Mayow in 1660s established that combustion and respiration are only possible in the presence of air [210]. French chemists Lavoisier and Sequin's determined that respiration and combustion involved the consumption of oxygen (VO_2) and formation of carbon dioxide [211]. The French researchers used a calorimeter, which estimates the heat produced per unit of carbon dioxide formed, to discover equivalence between heat produced during combustion and carbon dioxide formed (VCO_2) during respiration [187]. Consequently, physical activity levels are determined by energy expenditure using either direct calorimetry which measures body heat loss or indirect calorimetry which uses formulae to estimate energy expenditure from VCO_2 and VO_2 measurements [187].

Determining energy expenditure using direct and indirect calorimetry is impractical when assessing the physical activity of free-living populations [188]. Doubly labelled water is safe, accurate and effective for assessing the physical activity of free-living populations but costly and can only measure total energy expenditure [212]. Heart rate monitoring is generally considered unsuitable for measuring physical activity because of large errors and individual differences in heart rate at a given exercise intensity [213]. Pedometers are a low cost method for estimating daily ambulatory activity but do not measure activity intensity or estimate energy expenditure reliably [214]. Self-report physical activity questionnaires are a low cost method for assessing physical activity in large populations but are subject to recall bias and underestimate energy expenditure [215].

For this thesis, the Actical accelerometer was the physical activity monitor of choice. The Actical activity monitor is an omni-directional accelerometer that records step activity counts and estimates energy expenditure for up to 22 days. Actical accelerometers are lightweight, compact in size, unobtrusive to wear and provide acceptable estimates of energy expenditure [216]. The Actical accelerometer is a valid tool for measuring physical activity in children and suitable for large scale studies [217]. Physical activity guidelines for children recommend either 60 minutes of moderate-vigorous activity [8] or daily step volumes of 13,000-15,000 for boys and 11,000-12,000 steps for girls [218]. The Actical accelerometer records activity as step and accelerometer counts in 15, 30 and 60 s epochs allowing analyses of physical activity that include step counts, and accelerometer counts at different intensities of activity.

Figure 1.2. Actical accelerometer.

Choice of design

The URBAN Study is a stratified, cross-sectional research design, collecting data across four New Zealand cities. Within each city, 12 neighborhoods were selected using geographical information system protocols based on higher or lower walkability and high or low proportion of indigenous Maori residents. Within each of the 48 selected neighborhoods, 42 households were randomly selected and an adult (and where possible a child) was recruited into the study. In total 2032 adults were recruited into the study, half of the families (n= 976) had children (n= 1903, <18 y), 26% of families (n= 538) had children of eligible age (n= 819, 5-12 y) and from these 57% (one child per household, n= 308) joined the study. Data collected included: objective and self-reported physical activity, neighborhood perceptions, demographics, and body size measures. Other aspects of the study include an audit of the neighborhood street environment and a neighborhood-walkability score [206].

The “Power of Play” crossover design intervention was implemented for seven weeks in a single school-term providing children with free access to play and sport equipment during an optional supervised play period before school 08:00-09:00 and during class breaks (Figure 1.3.). Two weekend and five school days of Actical 15-s accelerometer data were collected pre and post implementation of the play intervention at each school.

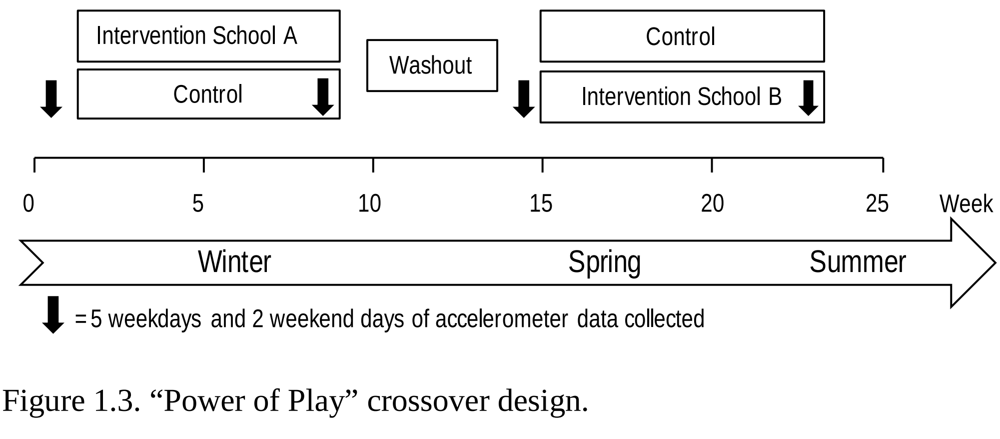


Figure 1.3. “Power of Play” crossover design.

Choice of analysis

Results in this thesis are presented with 90 and 99% confidence limits rather than the more common P-values. The use of the "null hypothesis" to determine significance suggests that for every 20 associations one result that is "significant at P = 0.05" will occur by chance alone or be considered non-significant when effects were of practical importance [219]. To avoid being misled by null-hypothesis testing confidence intervals of 90% and 99% are shown, which implies that an outcome is clear, thereby allowing clinical or practical importance to be interpreted from the confidence interval [219-220]. Use of 90% and 99% rather than 95% discourages readers from reinterpreting the outcome as significant or non-significant at the 5% level [219].

Mixed models (containing both fixed and random effects) were used to analyse step counts, which are useful for repeated measures, dealing with clusters (neighbourhood) and missing values (accelerometer data) [221]. Raw step counts were used in all analyses, because log transformed counts showed greater non-uniformity of the residuals than non-transformed counts. Non uniformity of effect or error in linear models can produce incorrect estimates and confidence limits so log transformation is used to make the data more normally distributed [220].

The fixed effects in the mixed model included main effects to adjust for city (four levels), maximum daily ambient temperature (simple numeric), daily rainfall (two levels, presence or lack of rain), and gender (two levels, but some analyses were repeated separately for boys and girls). Hour of the day was also a nominal main effect with 17 levels (0600 through 2200), and each hourly observation was weighted by the number of recorded minutes; means and effects derived from the mixed model thereby adjusted for missing and incomplete hourly recordings (accelerometer not worn).

Random effects were the child identity and the interaction of child identity with hourly period and with the child's numbered day of recording (1st, 2nd, etc.) to account for the levels of repeated measurement on each child. The random effect for child provided a standard deviation shown in tables and graphs representing true or stable differences between children over the monitoring period; this standard deviation (SD) represents an average of the between-child standard deviations in the age and predictor tertile groups (nine SD in total).

Generalized linear mixed modelling, realized with Proc Glimmix in SAS, was used to perform similar analyses for the time spent in the three activity intensities (sedentary, light and moderate-vigorous). The dependent variable was hourly observations of the number of each child's minutes in the given intensity. The logit link function and the binomial distribution were invoked to effectively specify logistic regression, and the fact that individual minutes spent at different intensities were not independent was taken into account by estimating an over-dispersion factor. The resulting distribution of the dependent variable is called pseudo-Bernoulli (see Example 38.1 in the Proc Glimmix documentation). The residual was specified in a manner that estimated the over-dispersion factor. Mean levels of activity were derived by back-transformation of the estimates from the logistic model (log transformed mean estimates were back transformed into mean raw units by raising 10 to the power of mean estimate [220]). These estimates of activity are shown in the figures as minutes spent per hour at different intensities, but in tables the means and effects are shown as minutes per period (the hourly mean multiplied by the number of hours). The between-child standard deviation (SD) was an approximation derived from the random effect for child; values of the SD in figures and tables differ between tertiles of the predictor, because the computation of the standard deviation from the logistic model depends on the value of the mean.

The inference about the true value of a given effect (a difference in means) was based on its uncertainty in relation to the smallest important difference, which was determined by standardization as 0.20 of the pure between-child standard deviation within the two compared subgroups [220]. Assessment of magnitude of differences in time spent was performed with the means and standard deviation of the logs of the odds of being active at a given intensity. The odds ratio is the probability that the event of interest (being active) occurs to the probability that it does not occur expressed as a ratio [222]. Odds ratios tend to have a skewed distribution so the log of the odds ratio was used to provide an approximately normal distribution [222]. Hence the effects of the predictors of interest (the five GIS and four street-audit measures) were examined with logistic regression using the log of the odds of being active at a given intensity.

We used the mechanistic (non-clinical) version of such inference: the effect was deemed unclear if the uncertainty represented by the 90% confidence interval included smallest important positive and negative differences; the effect was otherwise deemed clear. Effects that were clear with the more conservative 99% confidence interval are also indicated, because for such effects there is less inflation of error arising from the large number of inferences in this study. For this reason, uncertainty in the estimate of each effect is also shown as a 99% confidence interval.

Results in tables and figures of continuous built environment variables (e.g., housing density per km^2) are presented as tertiles to illustrate the relationship between the variable of interest and physical activity levels. Quantiles are regularly used in epidemiological studies to compare relative risk between groups [223] and may be useful to evaluate effects of built environment variables on children's physical activity (e.g. exposure to high, medium and low levels of traffic). Analysing a continuous variable in several equal groups of subjects avoids the assumption that there is a linear relationship between variables and the outcome of interest [224].

Bootstrapping or resampling was used to calculate confidence limits in the crossover play intervention to provide an estimate of certainty in the outcome statistics of the small sample when applied to the general population [225]. The arcsine-root transformation was used because it produced uniform errors across all intervals. Estimates were back transformed and expressed as time spent at different intensities in each setting. Any slight mismatch between the back-transformed effects and the differences in the means arising from the use of the non-linear arcsine root transformation were adjusted so that time spent in different intensities and settings totalled 100%. Inferences were based on standardised magnitude thresholds [220] using 1000 bootstrap samples; uncertainty in effects was expressed as 90% confidence intervals.

ORIGINALITY OF THE THESIS

- The quantitative literature review of objectively measured built-environment effects on children's objectively measured physical activity used a systematic approach to evaluate studies in lieu of a meta-analysis, which was not feasible owing to different methods used in the reviewed studies.
- This is the first study in New Zealand at a national scale where the effects of a comprehensive set of objectively measured built environment variables on children's objectively measured physical activity were determined.
- In addition, this is one of the first international studies to report effects of the built environment using multiple neighbourhood comparisons.

- No previous studies have objectively measured the mean cadence of steps accumulated at moderate-vigorous intensity for free-living children.
- This is the first study to evaluate the longitudinal (30 months) effects of seasonal weather in multiple geographical locations on children's accelerometer-derived step activity at light and moderate-vigorous intensity.
- The Power of Play intervention study was the first New Zealand study to introduce unstructured play as a method to encourage children to self-determine play to increase daily physical activity.
- No previous studies have examined the effect of threshold and interval on the Actical accelerometer on the proportion of physical activity classified as sedentary, light or moderate-vigorous intensity.
- No previous studies have investigated the effect of compliance and other factors on activity data loss in an intervention study.

THESIS ORGANISATION

This thesis consists of eight chapters (Figure 1.4.). Chapter one is the introductory chapter to the thesis and provides an overview of the main issue of childhood obesity and considers different intervention approaches to increase children's habitual activity. In Chapter one it was identified that interventions need to have enduring effects on children's activity behaviours and that it may be beneficial to modify the built environment as a potential long-term health strategy. A previous review of built-environment effects on children's activity determined that effects of the built environment on objectively measured physical activity were unclear [143]. In Chapter two a quantitative and updated literature review is undertaken of objectively measured built-environment effects on children's objectively measured physical activity. The studies examined in Chapter two revealed disparate effects of neighbourhood walkability and traffic infrastructure on children's habitual activity along with issues of using accelerometers to measure activity. Chapter three examines the disparate effects on children's activity identified in Chapter two using a comprehensive set of objective measurements of the built environment including a pedestrian street-audit instrument [226] and geographical information system data. Chapter 4 uses a similar study design as Chapter 3 to investigate children's pattern of daily activity as accelerometer steps. In Chapter one children's play was identified as an important way for children to accumulate daily physical activity. A crossover-design play intervention was implemented to develop beneficial play and physical activity behaviours and results are reported in Chapter 5. Accelerometer measurement issues of data loss and thresholds identified in Chapter two are examined in Chapters six and seven respectively. The final Chapter summarises and discusses the important findings arising from the thesis. The thesis is organised into an introductory chapter, an updated review of built environment effects on children's activity, two built environment studies and a play intervention. From the intervention study, two sub studies were subsequently conceptualised to investigate the accelerometer measurement issues of thresholds and data loss.

Chapter One

Introduction: Intervening to increase children’s daily activity

Aim: To provide an overview of the literature on childhood obesity and physical activity to identify potential research questions and strategies to increase children’s habitual activity.

Question: Why and where to intervene to increase children’s daily physical activity?

Chapter Two

Effect of the built environment on children’s moderate-vigorous physical activity

Aim: To review studies linking aspects of the built environment with children's moderate-vigorous physical activity

Question: What is currently known about effects of the built environment on children’s physical activity?

Chapter Three

Effects of neighborhood infrastructure on physical activity in New Zealand children

Aim: To determine the strength of associations between GIS measures of the residential neighbourhood and children’s physical activity.

Question: What built environmental features predict New Zealand children’s habitual physical activity?

Chapter Four

Children’s step counts at light and moderate-vigorous intensities during school and non-school days

Aim: To determine the effect of meteorological variables on children’s steps accumulated at light and moderate-to-vigorous intensity.

Question: What are the effects of darkness, rainfall, and temperature on children’s physical activity?

What proportions of children’s steps are accumulated at different intensities on school and non-school days?

Chapter Five

Power of Play: A Primary School Intervention to increase physical activity in New Zealand children

Aim: To implement an intervention to increase children's physical activity by providing play and sport equipment for children to engage in self-directed play before school and during class breaks.

Question: Is a play intervention at school a short-to-medium term solution to increasing physical activity in New Zealand children?

Chapter Six

Examining loss of activity data in accelerometer studies with children

Aim: To examine reasons for children's non-compliance and other factors that affect data loss in accelerometer studies.

Question: What factors affect the proportions of valid physical activity data in children's accelerometer studies?

Chapter Seven

Accelerometer sampling interval and intensity thresholds effect on measures of children's physical activity

Aim: To compare children's physical activity using different thresholds and sampling intervals.

Question: How do children's proportions of time at different activity intensities compare when using manufacturer thresholds at 60-s intervals, with thresholds of Puyau and colleagues at 60-s and 15-s intervals?

Chapter Eight

Discussion: Evaluating urban environments for children's activity

Figure 1.4. Schematic of the thesis structure.

CHAPTER 2: EFFECT OF THE BUILT ENVIRONMENT ON CHILDREN'S MODERATE-VIGOROUS PHYSICAL ACTIVITY

This chapter comprises the following paper submitted to Sports Medicine: McGrath, L. J., Hopkins, W. G., & Hinckson, E. A. (2013). *Manuscript submitted for publication.*

ABSTRACT

Background: Understanding which attributes of the built environment influence children's habitual physical activity can inform urban design. **Objective:** To review studies linking aspects of the built environment with children's moderate-vigorous physical activity. **Methods:** We searched for articles published between January 2000 and March 2013 that included measures of children's activity using accelerometers in combination with location data from geographical information systems (GIS), street-audit measures, or global positioning systems (GPS). Magnitudes of effects were evaluated by standardization. **Results**: Of 482 potentially relevant articles, 30 met criteria for detailed evaluation, but only 22 (involving 5,048 children, age 8-18 y) provided sufficient data to derive effects as differences in minutes of moderate-vigorous activity between defined urban settings. In 14 studies with GIS or street audit measures, parks, playgrounds, green space areas, recreational facilities, sport grounds and schools near residential dwellings had at most small positive effects on overall moderate-vigorous activity, presumably through play. Walking paths had small effects on adolescent girl's activity. In contrast, traffic infrastructure (intersections, roads, traffic lights, speed humps and traffic-calming devices) had small-moderate negative effects, reflecting concerns about safety. A large difference between daily moderate-vigorous activity of adolescents living in metropolitan areas (56 min) and their suburban and rural counterparts (24 and 23 min) was entirely attributable to walking (GPS monitored) inner-city streets. In one GPS study, walking to school produced small increases in activity compared with transport by car or bus. In other GPS studies, greater proportions of activity took place in streets and urban venues (40-80%) than in green spaces (20-50%), and more than half of children’s outdoor moderate-vigorous activity occurred with a parent nearby. **Conclusions:** Planners and developers need to design pedestrian-safe cities that encourage parents to allow children’s neighbourhood walking, independent mobility, and play.

INTRODUCTION

The built environment has the potential to affect the long-term health of most children by increasing the daily physical activity they experience through independent mobility and play [6-7]. Planners, developers and central government are more likely invest in changes to city infrastructure if there is evidence that specific built-environment elements contribute to habitual physical activity [6, 227]. Although evidence can be provided by self reports, objective measures of built-environment settings, locations and physical activity have fewer biases [215, 228]. This review is focused on objectively measured evidence for aspects of the built environment that have effects on children's habitual physical activity.

The built environment can be quantified using geographical information system (GIS) analysis to provide spatial measures of population demographics, land-use mix, road infrastructure, pedestrian infrastructure, and various kinds of amenity, all of which could affect habitual physical activity [229-230]. A limitation of GIS analyses is comparability of the measures between studies, which could be addressed by the use of generic measures [231] or by reporting sufficient data to allow derivation of generic measures. Street audits, where researchers survey the built environment in person, have also provided estimates of walkability, neighbourhood aesthetics, pedestrian safety and other potentially important measures, although several studies have calculated these measures using GIS [226, 231-232]. In this review we have included studies using GIS or street-audit measures to relate children's neighbourhoods to habitual activity.

Lightweight portable devices that access the global positioning system (GPS) produce geographical coordinates at sampling intervals of 1-60 s, which can be imported into GIS software and plotted as time-stamped locations on GIS maps [233]. Studies combining GPS and GIS technology with a parallel stream of physical activity data have the potential to improve our understanding of where and when children are active [234-235]. The major limitations of using GPS have been signal loss and inadequate recording time, but advances in the technology have increased the amount of useful data through improvements in battery life, start-up time, positional accuracy, and indoor as well as outdoor reception [235]. GPS studies have been included in this review, in spite of their limitations.

Children’s free-living physical activity can be assessed objectively using accelerometers, pedometers, or double-labelled water. Accelerometers have been recommended, because they provide a measure of intensity as well as a time-stamped data stream that allows periods of non-wearing to be taken into account in the analysis [212]. Pedometer step counts provide a measure only of children’s daily physical activity volume [236-237] and no indication of when the device was worn. There have been no studies of the effects of built environment using double-labelled water. Most studies have used accelerometers to quantify time spent at moderate-vigorous intensity, presumably because guidelines for minimum daily duration of children's activity are available only for this intensity. Effects on non-sedentary activity (light plus moderate-vigorous) and on daily step counts (representing stepping at light and moderate-vigorous intensities) have also been reported in several studies and are included in this review. A previous review had concluded that the effects of objectively measured built environment attributes on objectively measured physical activity were unclear [143]. The purpose of this review is to provide an update using GIS or street-audit measures to relate children's neighbourhoods to accelerometer and pedometer measured habitual activity combined with GPS data where possible.

METHODS

Eligibility criteria

Published journal articles that examined relationships between children’s accelerometer or pedometer measured physical activity and features of the built environment near their homes were considered for inclusion. "Children" were defined as youth of age 5-17 y. The neighborhood environment had to be assessed using an objective measurement tool–either geographical information system (GIS) analyses or a street infrastructure audit. We excluded studies that examined GIS data for city-wide rather than neighbourhood areas and studies that used school location as a proxy for residential neighbourhood. Studies had to include a built-environment predictor measured either as a continuous variable (e.g., speed humps per km^2) or a dichotomous variable (e.g., park present or not within 400 m of home). We included articles that used GPS technology to assess places where children were active. Several longitudinal studies were included, but only the cross-sectional aspects of their data were analysed. Articles not written in English and those published prior to 2000 were excluded.

Search strategy and identification of studies

MEDLINE via PubMed, EMBASE, and CINAHL databases were searched for studies published between January 2000 and April 2013. Search terms included child, student, adolescent, teen, or youth combined with physical activity and other terms accelerometer, geographical information system, GIS, global positioning system, GPS, neighbourhood built environment, urban, environment, connectivity, walkability, land-use mix, pedestrian, and traffic. After completing the search of titles and abstracts, 480 potentially relevant articles were identified.

Analysis of reviewed studies

The selection process shown in Figure 2.1 identified 30 relevant articles for in-depth assessment. We examined each study for objectively measured built-environment predictors that might relate to children's physical activity. Eight studies met the inclusion criteria but provided insufficient data to enable estimation of minutes of activity. Reasons for excluding these otherwise useful studies are shown in Table 2.1. Of the remaining studies, 13 combined GIS and/or street audit measures with accelerometer derived physical activity data, while nine combined GIS, GPS and accelerometer data.

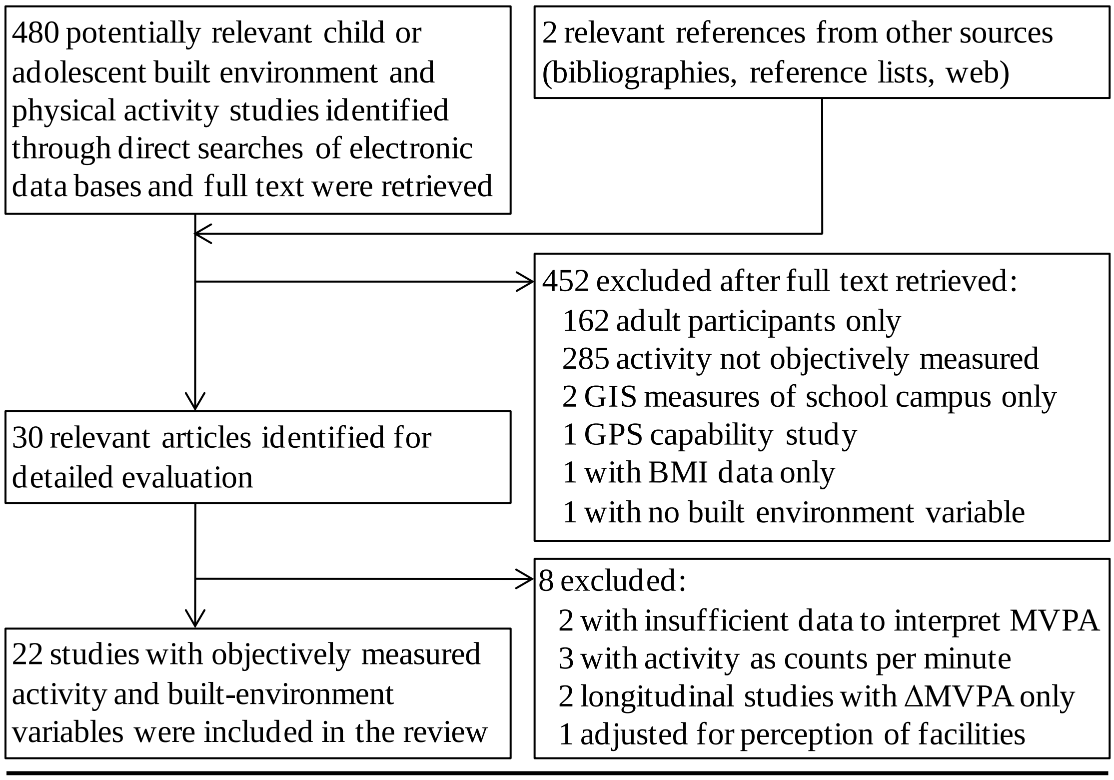


Figure 2.1. Study selection flowchart.

In the 22 included studies, built-environment features were analyzed either as dichotomous variables (examples: reside in a new vs an old suburb; at least one recreational facility present within 1600 m versus absent; perform walk to school vs car ride) or as simple numeric linear variables (examples: distance to school in km; walkability index). We present the effect of each dichotomous variable as the difference in activity (in minutes and as a percent of the total activity) between the two levels of the variable. In only one study [238] effects were presented directly as mean minutes of daily moderate-vigorous activity; for others we estimated activity from reported coefficients and weekly totals. The effect of a numeric variable is presented as the difference in values of activity predicted by values of the variable separated by two standard deviations (2SD) of the variable; in all cases these effects were calculated either directly from the beta coefficient or from the correlation coefficient (r) between physical activity (Y) and the variable (X), using the formula $\Delta Y/SD_Y = r.\ \Delta X/SD_X = 2r$.

The use of two SD to gauge the effect of variables ensures congruence between threshold magnitudes for correlations and standardized differences [220]. Examples of 2SD of an urbanisation measure is 50 more intersections per km^2 or 2SD provision of an amenity is 15 more sport venues within 2 km of participant residences. The magnitude of each effect was evaluated by standardization: the difference in means divided by the between-child standard deviation using the following scale: <0.20, trivial; 0.20-0.59, small; 0.60-1.19, moderate; ≥1.20, large [220].

Table 2.1. Studies that met inclusion criteria for effects of built environment on children's physical activity but were subsequently excluded for reasons related to data presentation or analysis.

Study	Effect in the study	Reason excluded
McDonald 2012 [239]	Recreational facility present	Difficult to interpret unique neighbourhood types produced by cluster analysis
Rodriguez 2012 [240]	Parks, schools and food outlets present	Can't convert the odds ratio for MVPA vs sedentary into min of activity
Cooper 2010 [241]	Time outdoors	Activity expressed as counts per min
Quigg 2010 [242]	Time spent in parks	Activity expressed as counts per min
Roemmich 2006 [243]	Housing density and recreation area	Activity expressed as counts per min
Carver 2010 [244]	Road safety features	Difficult to convert ΔMVPA into min of activity
Crawford 2010 [245]	Reside in cul-de-sac	Difficult to convert ΔMVPA into min of activity
Scott 2007 [246]	Availability of facilities	Inappropriate to adjust for perception of availability

MVPA = moderate-vigorous physical activity in minutes; **SD** = standard deviation; **ΔMVPA** = longitudinal change (delta) in moderate-vigorous physical activity.

RESULTS / DISCUSSION

Quality of the included studies

An assessment of the quality of the included studies is shown in Table 2.2. Studies were appraised using the following criteria: sample size, gender representation, number of days of recording of data, objective neighbourhood assessment (GIS or street-audit), participation rates, missing data (proportion of days devices were worn), and adjusting for missing data, weather, demographics and clustering. The criteria had 2-5 levels scored as integers, as shown in the footnote of Table 2.2. Uncertainties in scoring several items were resolved by discussion between the authors.

Participation rates at recruitment ranged from 27% to 94% in 17 studies, while five studies did not include this information. All studies reported the final sample size and the proportion of these participants providing data for analysis (range 38% to 96%). The proportion of missing location data reported in GPS studies ranged from 18% to 81%; the lower proportions occurred in studies using the BT-335 GlobalSat [247-248], Gamin Forerunner 205 [249] and EM-408 [250] models of GPS receiver that use the SiRFstarIII GPS chip, which works indoors reliably. The longer battery life of the BT-335 (allowing for 25 h of GPS data before recharging) also reduced data loss. In only two studies the accelerometer non-wear time was stated explicitly [247-248]. For the others we estimated non-wear time either from proportions of participants providing matched GPS-accelerometer data or from exclusion criteria and final sample size used for analysis. The range of accelerometer non-worn days was 18-85%. Four GIS studies accounted for missing accelerometer data, two by using imputation [251-252] and the others by multiplying the original values by the inverse of the percent total time reported [253-254].

Demographics are potential confounders of relationships between the built environment and physical activity in adults, because of the differing opportunities or expectations for physical activity in different social strata [255-256]. Most studies in this review made adjustments for demographics, but we included all studies reporting simple bivariate relationships between built-environment variables and activity. Adjustment for clustering within neighbourhoods or schools addresses the issue of interdependence of the data from participant clusters and would likely affect only the statistical significance rather than the magnitude of an effect. In three studies [257-259] there were negligible effects of geographical clustering.

The total quality score shown is the sum of the item scores rescaled to a percent score (range 0-100%). The scores were limited by small sample size, too few days of recording, low participation rates at recruitment, high rates of missing data and lack of adjustment for confounders. The quality scores were higher for GIS or street-audit studies than for GPS studies (62 ± 10 % and 52 ± 14 %, respectively; mean ± SD), mainly because the GPS studies had greater proportions of missing data.

Table 2.2. Quality of the studies included in this review.

Study	Sample size[a]	Sample gender[b]	Days of recording[c]	GIS data[d]	Participation rate[e]: Agreed to join	Participation rate[e]: Provided data	Activity data[f]	GPS data[g]	Adjustments for…: Missing data[h]	Adjustments for…: Weather[i]	Adjustments for…: Demographics /clustering[j]	Total score[k] (%)
Studies defining built-environment variables with GIS or street audit												
Carver 2008 [257]	3	1	2	1	1	2	2	-	0	0	2	61
Dowda 2007 [251]	4	0	2	1	1	3	3	-	2	0	2	78
Jago 2005 [253]	2	0	1	1	0	3	2	-	2	0	2	57
Jago 2006 [254]	2	0	1	1	0	3	2	-	2	0	0	55
Maddison 2010 [260]	2	1	1	1	3	2	2	-	0	0	0	52
Patnode 2010 [259]	2	1	2	1	0	3	2	-	1	2	2	70
Prins 2011 [261]	2	1	2	1	1	1	2	-	0	0	2	52
Ries 2009 [262]	3	1	2	1	2	3	2	-	1	0	2	74
Roemmich 2007 [263]	1	1	2	1	1	3	2	-	0	0	1	52
Scott 2007 [252]	4	0	2	1	1	3	3	-	2	0	2	78
Stevens 2011 [264]	2	1	1	1	2	3	2	-	1	2	0	65
Timperio 2008 [258]	3	1	2	1	1	2	2	-	0	0	1	57
Van Dyck 2009 [265]	2	1	2	1	2	3	2[l]	-	0	0	0	57
Studies defining built-environment locations with GPS												
Almanza 2012 [247]	2	1	2	1	2	2	2	2	1	2	1	69
Cooper 2010 [238]	2	1	0	0	2	2	3	0	2	1	0	50
Dunton 2012 [248]	2	1	2	0	0	3	2	3	1	0	1	58
Jones 2009 [249]	2	1	1	0	1	1	2	2	1	0	0	42
Lachowycz 2012 [233]	3	1	1	0	2	2	1	1	1	1	0	50
Oreskovic 2012 [266]	0	1	2	0	0	3	2	0	1	1	0	38
Rainham 2012 [250]	3	1	2	1	1	3	3	3	1	0	0	69
Southward 2012 [267]	1	1	1	0	1	2	1	1	0	0	0	31
Wheeler 2010 [268]	4	1	1	1	2	3	1	2	0	2	1	65

GIS = geographical information systems; **GPS** = global satellite positioning; **MVPA** = moderate-vigorous physical activity in minutes.

[a]Sample size representative/sufficient: **0** = <50; **1** = 51-100; **2** =101-300; **3** = 300-700; **4** = >700.

[b]Gender: **0** = single; **1** = both.

[c]Total days of recording: **0** =2; **1** =3-4; **2** = >4.

[d]Neighbourhood characteristics were defined objectively: **0** = no; **1** = yes (either GIS or street-audit)

[e]**0** = <25% or not reported; **1** = 25-49%; **2** = 50-75%; **3** = >75%. Rate for providing data is percentage of those who agreed to join the study.

[f]Accelerometer worn days; **0** = <25%; **1** = 25-49%; **2** = 50-75%; **3** = >75%.

[g]GPS data matched with accelerometer data; **0** = <25%; **1** = 25-49%; **2** = 50-75%; **3** = >75%.

[h]Missing data: **0** = not reported; **1** = reported, not adjusted; **2** = reported + adjustment or data loss had negligible effect.

[i]Weather data: **0** =not reported; **1** = reported, not adjusted; **2** = reported + adjustment.

[j]Adjustment for demographics and clustering: **0** = neither; **1** = either; **2** = both.

[k]Sum of individual scores rescaled to 0-100% (min-max possible range: 0-23 for GIS and street-audit studies; 0-26 for GPS studies).

[l]Step counts in Van Dyck 2009 [265] were assessed as MVPA.

Study participants

Subject characteristics of study participants are shown in Table 2.3. All studies included in the review were published after 2005 and originated from United States of America (11), England (5), Australia (3), Belgium (1), Canada (1) and New Zealand (1). In all there were 5,048 participants (8-18 y). In 13 studies there were 3,165 children (8-12 y), in four studies there were 662 adolescents (≥13 y) and five studies were of children (1221) spanning the two age categories. The mean sample size for all studies was 358 (range 24-1525). Nine studies [233, 238, 247-248, 257-258, 261, 267-268] included children from subgroups of three projects, two studies were conducted on a cohort of girls [251-252], two studies involved the same sample of boys [253-254] and in the remaining studies [249-250, 259-260, 262-266] children were recruited from independent samples. Most children were recruited in schools (84% of studies); others were recruited during clinic visits, by phone, or by advertisements in the mail, in newspapers and on websites.

Table 2.3. Characteristics of the subjects who provided data for the analyses in the studies included in this review.

Study	Project	Sample (n)	Female (%)	Age range (y)	Country	Location	Socio-economic status	Population	Adjustment for characteristics and clustering
Studies defining built-environment variables with GIS or street audit									
Almanza 2012 [247]	PLACES	143	51	8-14	USA	Chino	mid	general	A,B,G,I,R
	PLACES	65	54	8-14	USA	Chino	high	general	A,B,G,I,R
Carver 2008 [257]	CLAN (child)	188	56	8-9	Australia	Melbourne	mixed	general	U;C[a,b]
	CLAN (teen)	346	47	13-15	Australia	Melbourne	mixed	general	U;C[a,b]
Dowda 2007 [251]	TAAG	1525	100	11-12	USA	Six States	mixed	69% White	B,I,R,S;C
Jago 2005 [253]	-	210	0	10-14	USA	Houston	mixed	43% White	A,B,E,R;C
Jago 2006 [254]	-	210	0	10-14	USA	Houston	mixed	43% White	-
Maddison 2010 [260]	-	110	43	12-18	New Zealand	Auckland	-	general	-
Patnode 2010 [259]	-	294	49	10-17	USA	Minnesota	mid-high	94% White	A,B,E,I,P,R,S;C[b]
Prins 2011 [261]	CLAN (teen)	209	54	13-15	Australia	Melbourne	mixed	general	G,E,U;C
Ries 2009 [262]	BALTS	316	59	14-18	USA	Baltimore	low-mid	69% Black	A,E,G,R;C
Roemmich 2007 [263]	-	88	50	8-12	USA	Erie	mid-high	88% White	A,B,G,I[a]
Scott 2007 [252]	TAAG	1525	100	11-12	USA	Six States	mixed	69% White	B,I,R,S;C
Stevens 2011 [264]	-	187	58	11	USA	Salt Lake	mixed	89% White	-
Timperio 2008 [258]	CLAN (child)	188	56	8-9	Australia	Melbourne	high + low	general	-;C[b]
	CLAN (teen)	346	47	13-15	Australia	Melbourne	high + low	general	-;C[b]
Van Dyck 2009 [265]	-	120	61	12-18	Belgium	Izegem	mixed	general	-
Studies defining built-environment locations with GPS									
Almanza 2012 [247]	PLACES	208	52	8-14	USA	Chino	mid + high	general	A,B,G,I,R
Cooper 2010 [238]	PEACH	117	54	11	England	London	mixed	general	-
Dunton 2012 [248]	PLACES	291	52	8-14	USA	Chino	mixed	43% Hispanic	A,B,G,I,R
Jones 2009 [249]	SPEEDY	100	53	9-10	England	Norfolk	low-mid	general	-
Lachowycz 2012 [233]	PEACH	614	53	11-12	England	Bristol	mixed	92% White	-
Oreskovic 2012 [266]	-	24	58	11-12	USA	Boston	mid	general	-
Rainham 2012 [250]	-	316	47	12-16	Canada	Nova Scotia	mixed	84% White	-
Southward 2012 [267]	PEACH	84	53	11-12	England	Bristol	mixed	92% White	-
Wheeler 2010 [268]	PEACH	1053	53	10-11	England	Bristol	mixed	92% White	A,B,I,W

A = age; **B** = BMI; **E** = education; **G** = gender; **I** = income or socioeconomic status; **P** = perception (self-efficacy); **R** = race; **S** = social support; **U** = urbanization (intersections, traffic lights, population density); **W** = weather or season; **C** = clustering.

[a]Authors [257, 263] performed some adjustments, but we have presented the unadjusted effects in Table 4, as well as the only reported adjusted effect in Roemmich 2007 [263].

[b]Authors found negligible effects of geographical clustering and did not adjust for it.

Study instruments

Details of the instruments used to define built-environment variables (GIS and street audits), physical activity (accelerometers) and locations of activity (GPS) are shown in Table 2.4. A detailed assessment of the validity of the different measures provided by the brands and models of the devices and of the GIS measures is beyond the scope of the present review, but our impression from these studies and other review articles [231, 235] is that most authors are confident about the validity of GIS, street-audit and GPS measures. With the accelerometers, again there seems to be general satisfaction that the "counts" provided by these devices have a reasonably close relationship with children's level of physical activity. However, as can be seen from the thresholds shown in Table 2.4, there is a wide range in the counts used to define the level of moderate activity, even for children of similar age. Differences in threshold between studies must produce differences in the time spent at different intensities. To allow better comparison of effects from different studies, we have therefore converted effects of the built environment expressed as minutes at a given intensity (or as steps) into proportions (%) of time spent at that intensity (or proportions of total steps). In studies with high count thresholds and therefore overall low minutes per day of moderate-vigorous activity, effects representing increases of only a few minutes translated into changes of as much as 400%. Expressing effects as standardized magnitudes appears to have eliminated such apparent inconsistencies in effects arising from different thresholds.

Table 2.4. Details of the use of neighbourhood assessment, accelerometers and the Global Positioning System (GPS) in the reviewed studies.

	Neighbourhood assessment		Accelerometer							
				Moderate threshold				Global Positioning System (GPS)		
Study	Instrument	Radius[a] (m)	Model	MET	Age range (y)	Counts per min	Epoch (s)	Model	Epoch (s)	Passive transport threshold
Studies defining built-environment variables with GIS or street audit										
Almanza 2012 [247]	ArcGIS 9.3	500	Actigraph GT1M	4	8-14	1470-2214[b]	30	-	-	-
Carver 2008 [257]	ArcView 3.3	800	Actigraph 7164	3	8-9	803-906[b]	60	-	-	-
	ArcView 3.3	800	Actigraph 7164	3	13-15	1400-1706[b]	60	-	-	-
Dowda 2007 [251]	ArcGIS 9.0	1600	Actigraph 7164	3	11-12	3000[c]	60	-	-	-
Jago 2005 [253]	Street-audit	-	Actigraph 7164	3	10-14	3200[c]	60	-	-	-
Jago 2006 [254]	ArcGIS 9.0	1600	Actigraph 7164	3	10-14	3200[c]	60	-	-	-
Maddison 2010 [260]	ArcGIS 9.3	-	Actigraph 7164	4	12-18	1930-2941[b]	60	-	-	-
Patnode 2010 [259]	ArcGIS 9.2	1600	Actigraph 7164	4	10-17	1684-2735[b]	60	-	-	-
Prins 2011 [261]	ArcView 3.3	400-2000	Actigraph GT1M	3	13-15	1400-1706[b]	60	-	-	-
Ries 2009 [262]	ArcGIS 9.1	1600	Actigraph 7164	3	14-18	1158[d]	30	-	-	-
Roemmich 2007 [263]	ArcGIS 10	800	Biotrainer Pro	-[e]	8-12	-[e]	60	-	-	-
Scott 2007 [252]	ArcGIS 9.0	1600	Actigraph 7164	3	11-12	3000[c]	60	-	-	-
Stevens 2011 [264]	Street-audit	-	Actigraph GT1M	3	11	1136[b]	30	-	-	-
Timperio 2008 [258]	Street-audit	-	Actigraph 7164	3	8-9	803-906[b]	60	-	-	-
	Street-audit	-	Actigraph 7164	3	13-15	1400-1706[b]	60	-	-	-
Van Dyck 2009 [265]	Street-audit	-	Yamax SW-200[f]	-[f]	-[f]	-[f]	-[f]	-	-	-
Studies defining built-environment locations with GPS										
Almanza 2012 [247]	ArcGIS 9.3	500	Actigraph GT1M	4	8-14	1470-2214[b]	30	BT-335 GlobalSat	30	>32 km/h
Cooper 2010 [238]	ArcGIS 9.2	-	Actigraph GT1M	3	11	3200[g]	10	Garmin Foretrex 201	10	travel diary
Dunton 2012 [248]	-	-	Actigraph GT2M	4	8-14	1470-2214[b]	30	BT-335 GlobalSat	30	>15 km/h
Jones 2009 [249]	ArcGIS 9.2	800	Actigraph GT1M	-	9-10	2000[h]	30	Garmin Forerunner 205	1-10	-
Lachowycz 2012 [233]	ArcGIS 9.2	-	Actigraph GT1M	3	11-12	2296[i]	10	Garmin Foretrex 201	10	>15 km/h
Oreskovic 2012 [266]	ArcGIS 9.2	-	Actigraph GT1M	3	11-12	1952[j]	30	Garmin Forerunner 201	3-55	>5 km/h
Rainham 2012 [250]	ArcGIS	-	Actigraph GT1M	3	12-16	1263-1880[b]	30	EM-408 SiRF III	1	>10 km/h
Southward 2012 [267]	ArcGIS 9.3	-	Actigraph GT1M	3	11-12	2296[i]	10	Garmin Foretrex 201	10	travel diary
Wheeler 2010 [268]	ArcGIS 9.3	-	Actigraph GT1M	3	10-11	3200[g]	10	Garmin Foretrex 201	10	>15 km/h

MET = metabolic equivalents (multiple of resting metabolic rate).
[a]Neighbourhood radius from the child's home; 400, 500, 800, 1,600, and 2,000 m equate to areas of 0.5, 0.8, 2, 4, and 12.6 km^2 respectively.
[b]Counts calculated for the lowest and highest age using the "Freedson" formula in the Actigraph software:
MET (3 or 4) = 2.757 + 0.0015*(counts per min)- 0.08957*(age in years)- 0.000038*(counts per min)*(age in years).
[c]Threshold derived by Treuth 2004 [269] for girls 13-14 y.
[d]Threshold adapted from that derived by Treuth 2004 [269] for girls 13-14 y.
[e]The moderate-vigorous threshold used was 1x acceleration of gravity
[f]Yamax digiwalker SW-200 pedometer was used to measure physical activity.
[g]Threshold derived by Puyau 2002 [270] for children aged 6-16 y.
[h]Based on mean count derived by Brage 2003 [271] for men treadmill walking at 4 km/h.
[i]Threshold derived by Evenson 2008 [272] for children 5-8 y.
[j]Threshold derived by Freedson 1998 [273] for adults.

Built-environment effects on physical activity

Table 2.5 shows the wide diversity in built-environment variables that have been investigated for their effects on children's physical activity. Some consistency emerges from the apparent dissimilarity of these effects when they are categorized as effects of play space, walkability and traffic-safety. In this section we also evaluate whether there were any consistent differences between effects analysed with and without adjustment for socio-economic status.

Play Space

In studies [251-252, 258, 260-263] that assessed the effects on neighbourhood activity where there were places for children to play (recreation facilities, gyms, parks, playgrounds, beaches, sports venues or schools), there were generally trivial-small increases in activity, representing 6 ± 13 % (mean ± SD) extra daily activity. Opportunity for play presumably also explains the large percentage increase (but small standardized increase) in moderate-vigorous activity of children living in a new suburb relative to that of children living in a conventional suburb with half the green space [247]; indeed, daily activity was higher for children from either suburb who spent more time in green space [247]. (The large magnitude of the percent effects in this study [247] appears to be due to the fact that the count threshold for intensity of moderate-vigorous activity was higher than in any other study; for this reason we did not group it with the other studies in this section).

Table 2.5. Effects of built environment on daily minutes of moderate-vigorous physical activity. Unless otherwise specified, the participants are boys and girls combined, and the monitored period is an average of week days and weekend days.

			Built-environment feature			Effect expressed as ΔMVPA			
Study (project)	Home location or participants, and monitored daily period	MVPA mean ± SD (min)	Description	Mean (range) or mean ± SD	Evaluated difference[a]	Mean (min)	Mean (% of MVPA)	Effect magnitude[b]	P value or 95% conf. limits (min)
Studies defining built-environment variables with GIS or street audit									
Almanza 2012 [247]	Old suburb[c], after school, 4 h	4.3 ± 8.6[d]	New suburb[c]	-	Reside	3	74	~small ↑[d]	0.05
Carver 2008 [257] (CLAN, child)	Boys, weekend, 15 h	170 ± 83	Intersections (per km^2)	45 (2, 128)	50	-69	-41	moderate ↓	<0.001
			Traffic lights (per km^2)	1.5 (0, 8)	3	-48	-29	small ↓	<0.001
			Road (km per km^2)	8 (0.8, 16)	5	-44	-26	small ↓	<0.05
			Walking track (m per km^2)	14 (0, 1850)	50	-3	-1	trivial	<0.05
	Girls, before school, 3 h	20 ± 18	Road density (km per km^2)	8 (0.8, 16)	5	-6	-31	small ↓	<0.01
			Intersections (per km^2)	45 (2, 128)	50	-7	-34	small ↓	<0.05
	Girls, weekend, 15 h	160 ± 78	Intersections (per km^2)	45 (2, 128)	50	-42	-27	small ↓	<0.05
			Traffic lights (per km^2)	1.5 (0, 8)	3	-49	-31	moderate ↓	<0.01
			Walking track (m per km^2)	14 (0, 1850)	50	-3	-2	trivial	<0.05
Carver 2008 [257] (CLAN, teen)	Boys after school, 3 h	27 ± 15	Cul-de-sac	-	Reside	9	32	small ↑	<0.05
	Boys weekday evening, 3 h	12 ± 9.5	Cul-de-sac	-	Reside	5	40	small ↑	<0.05
		12 ± 9.5	Speed humps (per km^2)	2.5 (0, 50)	10	4	35	small ↑	<0.05
	Boys weekday non-school, 9 h	50 ± 22	Cul-de-sac	-	Reside	10	20	small ↑	<0.05
	Boys, weekend, 15 h	72 ± 44	Cul-de-sac	-	Reside	22	31	small ↑	<0.05
		72 ± 44	Traffic slow points (per km^2)	0 (0, 12)	2	-21	-29	small ↓	<0.05
	Girls before school, 3 h	7.9 ± 5.3	Speed humps (per km^2)	2.5 (0, 50)	10	1	18	small ↑	<0.05
	Girls weekday non-school, 9 h	38 ± 17	Walking track (m per km^2)	0 (0, 2000)	50	4	11	small ↑	<0.05
Dowda 2007 [251]	Girls, ~12 h[e]	22 ± 15[f]	<1600 m to ≥1 rec. facility	68%	Present	1[f]	5	trivial	<0.001
Jago 2005 [253]	Boys, 18 h	25 ± 18	Walkable sidewalks	-[g]	-	5	18	small ↑	0.08
Jago 2006 [254]	Boys, 18 h	25 ± 18	Walkable sidewalks	-[g]	-	5	19	small ↑	>0.05

			Walking ease	-	-	1	3	trivial	>0.05
			Tidiness	-	-	1	5	trivial	>0.05
			Street access and condition	-	-	-4	-15	small ↓	>0.05
			Parks	-	-	2	-6	trivial	>0.05
			Gyms			0	2	trivial	>0.05
	Boys, 18 h	163 ± 52[h]	Walkable sidewalks	-	-	21	13	small ↑	<0.001
			Walking ease	-	-	-1	0	trivial	>0.05
			Tidiness	-	-	1	1	trivial	>0.05
			Street access and condition	-	-	-9	-6	trivial	>0.05
			Parks	-	-	-7	-4	trivial	>0.05
			Gyms			-2	-1	trivial	>0.05
Maddison 2010 [260]	≥400 m to park, ~18 h	76 ± 35[i]	<400 m[i] to park	-	Reside	12	16	small ↑	-4, 28
	≥400 m to playground, ~18 h	78 ± 39[i]	<400 m to playground	-	Reside	14	15	small ↑	-5, 33
	>1600 m to rec. centre, ~18 h	78 ± 39[i]	≤1600 m[i] to rec. centre	-	Reside	16	21	small ↑	-3, 35
	>1600 m to gym, ~18 h	76 ± 34[i]	≤1600 m to gym	-	Reside	14	18	small ↑	-3, 32
	>1600 m to beach, ~18 h	80 ± 38[i]	≤1600 m to beach	-	Reside	9	11	small ↑	-15, 33
Patnode 2010 [259]	Girls, 18 h	18 ± 12	Distance to school (km)	6.5 ± 6.6	10	-5[k]	-28	small ↓	0.03
			Walkability index	0.3 ± 2.4	5	7[k]	38	small ↑	0.02
Prins 2011 [261] (CLAN, teen)	~10 h[e]	41 ± 22	Sport venues within 400 m	0.5 ± 0.9	1.5	0	0	trivial	-40, 47
			Sport venues within 800 m	2.3 ± 1.9	3	0	0	trivial	-40, 48
			Sport venues within 2 km	15 ± 8.1	15	7	16	small ↑	0, 100
			Parks within 400 m	2.9 ± 2.0	4	5	13	small ↑	-22, 94
			Parks within 800 m	8.9 ± 4.0	8	0	0	trivial	-43, 50
			Parks within 2 km	41 ± 13	25	12	29	small ↑	0, 190
Ries 2009 [262]	~13 h[e,l]	42 ± 21	≤1600 m to ≥1 park	13 ± 13	20	6	14	small ↑	≤0.10
Roemmich 2007 [263]	Boys, 8 h[e]	186 ± 54	Houses/acre	7.5 ± 6.7	10	14	8	small ↑	>0.05
			Intersections/mile	5.6 ± 1.6	3	34	18	moderate ↑	≤0.05
			Street width (ft)	25 ± 12	20	-4	-2	trivial	>0.05

			Park area (%)	3.0 ± 5.4	10	11	6	small ↑	>0.05
			Rec. area (%)	0.5 ± 1.6	3	-18	-9	small ↓	>0.05
			Housing area (%)	43 ± 15	30	-16	-9	small ↓	>0.05
			Park/housing area (%)	9.3 ± 17	30	19	10	small ↑	>0.05
			(Park+ rec.)/housing area (%)	11 ± 18	30	14	8	small ↑	>0.05
	Girls, 8 h[e]	156 ± 41	Houses/acre	6.4 ± 4.6	10	15	10	small ↑	>0.05
			Intersections/mile	5.5 ± 1.5	3	12	8	small ↑	>0.05
			Street width (ft)	30 ± 7.7	15	-2	-1	trivial	>0.05
			Park area (%)	2.3 ± 4.1	8	-6	-4	trivial	>0.05
			Rec. area (%)	1.0 ± 4.4	8	7	4	trivial	>0.05
			Housing area (%)	47 ± 14	30	3	2	trivial	>0.05
			Park/housing area (%)	5.9 ± 12	20	-4	-3	trivial	>0.05
			(Park+ rec.)/housing area (%)	8.3 ± 15	30	2	1	trivial	>0.05
	8 h[e]	171 ± 48	Intersections/mile (adjusted)	5.6 ± 1.6	3	62	36	large ↑	≤0.05
Scott 2007 [252] (TAAG)	Girls, ~12 h[e]	22 ± 15[f]	<800 m to a locked school	42%	Present	-1	-3	trivial	0.40
			<800 m to school with amenities	39%	Present	-1	-3	trivial	0.42
			<800 m to a school	53%	Present	2	11	trivial	0.08
			<800 m to 1 or more parks	56%	4[m]	3[m]	12	small ↑	0.06
Stevens 2011 [264]	Low-walkable, after school, 5 h	46 ± 23	Mid-walkable	-	Reside	-2	-4	trivial	-
	Mid-walkable, after school, 5 h	44 ± 23	High-walkable	-	Reside	1	2	trivial	-
	Low-walkable, weekend, 13 h	30 ± 21	Mid-walkable	-	Reside	-4	-13	trivial	-
	Mid-walkable, weekend, 13 h	26 ± 23	High-walkable	-	Reside	6	23	small ↑	-
Timperio 2008 [258] (CLAN, child)	Boys, weekend, 15 h	170 ± 82	≥1 playground in public area	0.6 ± 0.5	Present	25	15	small ↑	6, 43
		170 ± 82	Path lighting in public area	15%	Present	-55	-32	moderate ↑	-95, -15
	Girls, after school, 6 h	73 ± 25	≥1 play facility in public area	1.0 ± 2.7	Present	-13	-18	small ↓	-26, 0
	Girls, weekend, 15 h	157 ± 80	≥1 play facility in public area	1.0 ± 2.8	Present	-44	-28	small ↓	-81, -7
Timperio 2008 [258]	Girls, after school, 6 h	31 ± 16	Public area with trees	61%	Present	6	19	small ↑	2, 10

(CLAN, teen)		31 ± 16	Public area with dog signage	29%	Present	7	22	small ↑	1, 13
Van Dyke 2009 [265][l]	Urban, 18 h (pedometry)	12.1 ± 3.7[n]	Suburban (less walkable)	-	Reside	1.4[n]	12	small ↑	0.06
Studies defining built-environment locations with GPS									
Almanza 2012 [247]	<1.5 min/d in green space	2.9 ± 5.8[d]	1.5-20 min/d in green space		Present	5	160	~small ↑[d]	0.001
			>20 min/d in green space		Present	12	400	~small ↑[d]	0.001
Cooper 2010 [238]	Boys car ride to school, 16 h	44 ± 17	Boys walk to school	-	Perform	8	16	small ↑	-
(PEACH)	Girls car ride to school, 16 h	31 ± 15	Girls walk to school	-	Perform	5	13	small ↑	-
	Car ride to school, 16 h	38 ± 17	Bus to school	-	Perform	2	5	trivial	-
	Boys car ride to school, 1 h[l]	3.3 ± 2.5	Boys walk to school	-	Perform	2	35	small ↑	<0.05
	Girls car ride to school, 1 h[l]	3.3 ± 3.4	Girls walk to school	-	Perform	2	40	small ↑	<0.07
	Car ride to school, 1 h[l]	3.3 ± 2.9	Bus to school	-	Perform	3	44	small ↑	<0.05
Rainham 2012 [250]	Suburban, outdoors	24[p]	Urban, outdoors	-	Reside	32[p]	57	moderate ↑	-
			Rural, outdoors	-	Reside	-1[p]	-4	trivial	-

MVPA = moderate-vigorous physical activity; **ΔMVPA** = effect of the evaluated difference in minutes and as a percent of the mean MVPA in the monitored period; **GIS** = geographical information systems; **GPS** = global satellite positioning.

[a]The built-environment variable is evaluated either as the effect of a dichotomous predictor (e.g., resident in new vs old suburb) or as the effect of a difference for a linear numeric predictor; the numeric difference shown was chosen by the present authors to be approximately two SD of the predictor.

[b]The standardized effect (ΔMVPA divided by the SD of the MVPA in the monitored period) was evaluated using the following scale: <0.20, trivial; 0.20-0.59, small; 0.60-1.19, moderate; ≥1.20, large [220].

[c]Old and new suburbs were defined as conventional neighbourhoods and smart-growth communities respectively; the new suburb had twice the green space of the old suburb [247].

[d]Estimate of SD based on Lachowycz 2012 [233].

[e]After school and weekend day.

[f]MVPA estimated from MET-minutes for 6 days, using mean MET=4.6 [251].

[g]Means and SD not provided in this study; effects derived from correlations.

[h]Data shown are minutes of non-sedentary time.

[i]Minutes of MVPA are summarized from data presented in Maddison 2010 [260].

[j]400 m and 1600 m are estimated distances for a 5- and 20-min walk respectively [260].

[k]Evaluated from bivariate correlations.

[l]Before school.

[m]Estimated SD for number of parks based on Prins 2011 [261].

[n]Data shown are steps (x1000) measured by Yamax digiwalker SW-200 [265].

[p]Personal communication from author [250]: minutes of MVPA are estimated using a mean of 3.5 days of data collected.

Walkability

There were trivial-small positive effects on children's moderate-vigorous activity in neighbourhoods evaluated as having more walkable sidewalks or better walkability by street-audit [253-254, 264] or GIS index scores [254, 259]. Provision of walking tracks in neighbourhoods had trivial effects on children's activity and a small positive effect on adolescent girl's activity [257]. Higher levels of daily activity of adolescents residing in less walkable suburban vs town-centre neighbourhoods [265] and higher levels of those living in metropolitan centres vs suburban and rural areas were attributed to additional daily steps involved in walking further to school and to extra walking (GPS monitored) on inner-city streets [250]. Another study with GPS-tracked walking to school found that there were small increases in daily activity compared with using transport by car or bus [238]. These effects of urbanisation involving walkability were trivial to moderate and represented an extra 7 ± 26 % of daily activity [238, 250, 253-254, 259, 263-265].

Traffic-safety

Adolescent boys who resided in cul-de-sac streets with no through-traffic or in neighbourhoods where there were speed humps to slow traffic displayed small increases in activity compared with other adolescent boys [257]; other traffic-calming barriers in the same study had small negative effects on the boys' activity, possibly because the barriers did not succeed in reducing traffic speed or volume. In contrast, there were small-moderate negative effects of any additional traffic infrastructure on younger children's activity, which have been attributed to parental concerns about child safety [257]. Traffic-calming barriers apparently do not reduce traffic flow enough to satisfy the parents of younger children that the streets are safe enough for independent recreation.

Adjustment for socioeconomic status

In the reviewed studies there is little difference in the magnitude of built-environment effects between studies that adjusted for socioeconomic status or education [247, 251-253, 259, 261-263] and those that did not [254, 257-258, 260, 264-265]. Thus, in Table 2.5, 14 of 34 effects (41%) with such adjustment are trivial in magnitude, whereas 14 of 45 (31%) without adjustment are trivial and the remaining effects with or without adjustment are mostly small. In the only project where adjusted and unadjusted effects were reported (in different articles) [253-254], effects on moderate-vigorous time were identical with and without adjustment, as were effects on non-sedentary time. The likely explanation is that any differences between residential areas in aspects of the built environment that affect objectively measured physical activity in children have little relationship to the socioeconomic status of the residents in those areas [274].

Children's activity in GPS-GIS defined settings

Adolescent studies that quantified activity within different built-environment settings using time-matched accelerometer activity data and GPS coordinates plotted on GIS maps are shown in Table 2.6. Walking local streets accounted for the greatest proportion of children's daily activity outdoors (37 ± 23 %; mean ± SD) [233, 249, 266-267]. A considerable proportion of activity took place in non-green space and other urban areas (26 ± 24 %) [233, 249-250, 266, 268]. Schools were an important setting for children's activity (18 ± 14 %) [250, 266], and a similar proportion of outdoor activity took place in parks, grassland, woodlands, beaches and other green space (17 ± 14 %) [233, 249, 266, 268]. Two thirds of children's outdoor activity took place with a parent nearby, suggesting that parents are an important facilitator of daily activity [248].

The fact that the standard deviations of moderate-vigorous activity are generally about twice as large as their means indicates that there are substantial differences between children's activity according to whether they visit a built-environment setting or not. More importantly, children with less activity at given settings could be targeted to increase their physical activity either by promoting visits to or providing more of these venues.

Table 2.6. Daily moderate-vigorous activity at GPS-GIS defined settings (outdoors unless stated otherwise).

Study (project)	Monitored daily period	Outdoor GPS data: Mean total time (min)	MVPA: Mean ± SD (min)	MVPA: Mean (% of total)	Setting	Moderate-vigorous activity: Mean ± SD (min)	Moderate-vigorous activity: Mean (% of GPS-MVPA)
Dunton 2012 [248]	After school + weekend	-	20 ± 16	-	Parent <50 m away	12.4	64
Jones 2009 [249] (SPEEDY)	Week and weekend	-	10.1	-	Home garden	2.4 ± 4.1	24
					Streets	1.9 ± 2.9	19
					Other hard surface	1.4 ± 2.7	14
					Farmland	1.4 ± 3.7	14
					Grassland	1.2 ± 3.2	12
					Indoors/other	0.7 ± 1.5	6.9
					Park or play area	0.7 ± 2.5	6.9
					Woodland	0.3 ± 0.7	3.0
					Beach	0.05 ± 0.4	0.5
Lachowycz 2012 [233] (PEACH)	After school	32	7.1	22	Green space	2.4 ± 4.8	34
					Streets	1.9 ± 3.2	27
					Road verge	0.2 ± 1.8	3
					Other	2.6 ± 4.4	37
	Weekend	52	7.6	15	Green space	3.5 ± 9.1	46
					Streets	1.6 ± 6.5	21
					Road verge	0.3 ± 2.7	4
					Other	2.2 ± 7.1	29
Oreskovic 2012 [266]	Week and weekend	47	15.5	33	Streets	6.4	41
					Home garden	5.2	34
					Park	1.7	11
					School	1.3	8
					Other	0.9	6
Rainham 2012 [250]	Week and weekend	-	56	-	Urban home	5.9	11
					Urban school	13.1	23
					Urban streets	31.5	56
					Urban other	5.6	10
		-	24	-	Suburban home	5.7	24
					Suburban school	5.3	22
					Suburban streets	9	37
					Suburban other	4.2	17
		-	23	-	Rural home	5.8	25
					Rural school	8.5	36
					Rural streets	5.6	24
					Rural other	3.4	15
Southward 2012 [267] (PEACH)	Boys before school	~60	14 ± 6.5	23	School walk	10 ± 5.6	71
	Girls before school		15 ± 8.1	25	School walk	11 ± 7.6	71
	Boys after school	~120	23 ± 13	19	School walk	13 ± 8.0	56
	Girls after school		21 ± 11	18	School walk	11 ± 8.6	53
Wheeler 2010 [268] (PEACH)	Boys after school	104	19	18	Non-green space	13	68
					Green space	4.5	24
					Other	1.5	8
	Girls after school	100	15	15	Non-green space	11	75
					Green space	2.6	17
					Other	1.2	8

MVPA = moderate-vigorous physical activity

CONCLUSIONS

Differences in the built environment had substantial positive effects on time children habitually spent performing moderate-vigorous activity mostly through opportunities provided by having local places to play, walkable neighbourhood streets and less dangerous traffic. The differences in urbanisation between rural, suburban and metropolitan centres did not predict children's daily activity because differences in activity in these centres were mostly related to built-environment characteristics that provided additional opportunity for walking. Parents are crucial in determining children's activity as they evaluate the built environment to decide whether to constrain roaming when the environment is too dangerous for independent recreation and facilitate physical activity by providing surveillance or being active with children. Objective GPS-GIS spatial information of where children are active reveals that children with permission seize opportunities to be active in all types of built-environment settings whether it is the street, non-green urban space or green space. The between-child difference in habitual physical activity in different GPS-fixed settings affirms the need for collaboration with city planners and developers to test urban designs that increase daily activity. The long term objective would be to provide neighbourhood play spaces and pedestrian networks that are either traffic-free or have design elements that prevent or drastically reduce vehicle-pedestrian collisions.

RECOMMENDATIONS FOR FUTURE STUDIES

To quantify year-round differences in effects of the built-environment on physical activity researchers should objectively measure children's GPS-tracked activity during seasonal weather changes. Children should be recruited from multiple GIS-defined neighbourhoods that differ in terms of play spaces provided, walkability and traffic-safety indicators. Select robust GPS watches that use low-power SiRFstarIV-V receivers capable of providing location data from mobile phone and Wi-Fi signals whenever satellite reception is blocked, thereby overcoming older device limitations of short battery-life and missing position-data. Use validated waterproof wrist-accelerometers that can be worn continuously to reduce participant burden and improve compliance so that more activity data is available for analysis. To ensure comparability between data provided from different accelerometer models report accelerometer counts and acceleration values (g) for the chosen MET thresholds. Where applicable future studies should include GIS measures of neighborhood demographics, amenity provision, building types, walkability, topography, vegetation indexes, vehicle-pedestrian collisions, road design and traffic infrastructure as numeric values or area (m^2) ratios per square kilometre [231]. More research is required that use parent-child accelerometer data collated with GPS-GIS information to examine motorized as well as non-motorized roaming to quantify children's dependent and independent mobility in all built-environment settings.

CHAPTER 3: EFFECTS OF NEIGHBORHOOD INFRASTRUCTURE ON CHILDREN'S PHYSICAL ACTIVITY

This chapter comprises the following paper submitted to American Journal of Preventive Medicine: McGrath, L. J., Hopkins, W. G., & Hinckson, E. A. (2013). *Manuscript submitted for publication.*

ABSTRACT

Background: Urban design can affect children's habitual physical activity by influencing active commuting and neighborhood play. **Purpose:** To examine associations between neighborhood infrastructure near children's residences and their objectively measured physical activity. **Methods:** Geographical Information System (GIS) protocols were used to select 2032 households from 48 low- and high-walkability neighborhoods within four New Zealand cities. Children (n=227; age 8.9 ± 2.6 y, mean ± SD) from the selected households wore accelerometers that recorded physical activity in 2008-2010. Multilevel linear models were used to examine the effects of five GIS and four street-audit measures of the residential environment (ranked into tertiles) on children's hourly step counts and proportions of time spent at different intensities on school and non-school days. **Results:** During school-travel times (08:00-08:59 and 15:00-15:59) children living in the mid-tertile distance from school (1.2-2.6 km) were more active than those in the other tertiles (1290 vs 1130 and 1140 steps·h^{-1}; true between-child SD 440); after school (16:00-17:59) children in the tertile closest to school were more active (890 vs 800 and 790 steps·h^{-1}; SD 310). Neighborhoods with more green space, attractive streets, or low-walkability streets had moderate positive effects on non-school day moderate-vigorous steps, whereas neighborhoods with medium-density housing, additional pedestrian infrastructure or more food outlets had moderate negative effects. Analysis of time spent at moderate-vigorous intensity produced similar outcomes. Other effects of residential neighborhood were unclear but at most small (based on 90% confidence limits). **Conclusions:** Modifying the urban environment to promote safe child-pedestrian mobility may increase children's moderate-vigorous physical activity.

INTRODUCTION

Understanding which attributes of the built environment constrain or encourage children's physical activity is essential to designing urban environments that promote active living [275]. Previous research has shown that one third of children in Australasian cities spent less than five minutes walking per day, few commuted by bicycle and families that owned a car walked less [116]. Child pedestrian injuries are implicated in low levels of walking owing to concerns from parents that children may sustain pedestrian-vehicular collisions while walking or playing on local streets and driveways [276-277]. Parents keep children safe by restricting independent mobility, outdoor play, and active transport [278-279]. However, well designed safe urban environments can ease parental restriction of neighbourhood play and active commuting [279]. It has been previously shown that provision of good quality sidewalks [253] and road safety elements; speed humps, chicanes or pedestrian crossing lights contribute to increased adolescent physical activity [244]. Children with permission to be in urban spaces, playgrounds, woodlands and parks accumulated a third of their daily satellite-tracked moderate-vigorous activity playing outdoors [268] and walking to school contributed three times more moderate activity than play in school grounds before class commenced [238]. Urban environment analyses using geographical information system (GIS) data found that increased street connectivity, greater land use diversity and access to parks predicted more adolescent daily activity [263]. In contrast, recent findings suggest that adolescent girls perform less habitual moderate-vigorous activity when residing near neighborhood food outlets or roads with high connectivity [240].

Others suggest that higher accelerometer-measured activity was associated with children's self-reported active play after school [280]. Children were more vigorously active on days when parents reported a visit to a friend's house, school ground, park, playground or their child played outside at home [281]. Satellite tracking identified that urban children roam close to home and are more active when outside in gardens or nearby streets [249]. However, a review of built environment studies found that children's self-reported but not objectively measured physical activity were associated with attributes of the urban surroundings and correlations with geographical information system or pedestrian environment data were unclear [143]. The purpose of this study was to examine children's accelerometer activity (step and accelerometer counts) associated with a comprehensive set of objective measurements of the built environment using a pedestrian street-audit instrument [226] and GIS data. The analysis was focused on three periods during which activity is potentially modified by the built environment: school commuting times, late afternoon on school days, and daylight hours during non-school days.

METHODS

Participants

Activity data were provided from school-age children (109 boys and 118 girls; age 9.3 ± 2.1; 5.1-13.0 y) recruited door-to-door in the Understanding the Relationship between Activity and Neighbourhoods (URBAN) cross-sectional study, which has been previously described in detail [206]. In brief, adults from 2032 randomly selected households from 48 neighbourhoods within four geographically diverse New Zealand cities enrolled in the study. Only one child per household meeting the age criteria (n=

819, 5-12 y) that resided with a recruited adult (n= 538) was eligible for recruitment (the child whose birthday was due next) and of these 308 joined the study. Twelve neighbourhoods within each city were selected that either supported or discouraged pedestrian mobility with higher or lower representation for Maori (New Zealand's indigenous people), which along with Pacific Island populations have elevated obesity-related health risk [13]. Neighborhoods were ranked as high or low walkable using Geographical Information Systems (GIS) measures of street connectivity, dwelling density, land-use mix and retail floor area [282]. Trained interviewers collected signed informed parental consent and child assent forms from participants. The ethnic proportions of the child participants were: European 72%, Asian 11%, and 17% Maori and Pacific Islanders.

Instruments

Geographic information systems

We extracted measures of neighborhood amenities from a Geographical Information System (GIS) database that used ArcGIS 9.3 software (Environmental Systems Research Institute, California) using methods previously described in detail [282-283]. In brief, GIS measures that might affect children's physical activity were selected; school travel distance and four indices of the residential environment; recreational amenities, food outlets, walkability, and dwelling density [206]. Neighborhood amenities more likely to affect adult rather than children's physical activity such as cafés, bars, restaurants and other commercial premises were not included in the analyses. Distance between home and school address for each participant was calculated using the ArcGIS 9.3 network analyst extension [282]. The recreational amenity index was formulated from the availability of green space, beaches and sports facilities within a walkable distance (800 m) of a neighborhood population-weighted centroid [282]. The neighborhood score for food outlets was derived by plotting the presence of supermarkets, petrol stations, bakeries, greengrocers, butchers, fishmongers, convenience and fast food stores within 800 m of the population centroid [282]. Each neighbourhood's walkability index was formulated by summing individual decile scores (1-10) of retail floor area, road intersection density, dwelling density and land-use mix that were ranked from data collected in the four cities [230, 282-283]. Dwelling density was calculated by dividing the number of dwellings by the residential land area [282]. Dwelling densities within 500 m of participant homes were ranked into a decile score (1-10) [282].

Street audit

The Systematic Pedestrian and Cycling Environment Scan (SPACES) [226] street-audit was adapted to measure New Zealand street infrastructure that facilitates neighborhood walking (see Figure 3.1). Twenty nine infrastructure items were added to the SPACES street-audit to better reflect the New Zealand pedestrian environment. Twelve road segments within each of the 48 neighborhoods were selected using GIS protocols [230]. Road segments were surveyed by one researcher for pedestrian-friendly qualities including footpath gradient and the provision of well-constructed footpaths and pedestrian shortcuts. The number of road lanes was used to assess local traffic volumes, and enforcement of the 50-$km \cdot h^{-1}$ speed limit was indicated by presence of traffic calming devices. Infrastructure affecting personal and pedestrian safety in each road segment was quantified by the presence of pedestrian crossing aids, surveillance from residences, streetlights, visible driveways, verge width, footpath obstructions, vandalism and graffiti. To determine whether the locality was pleasant for walking, the road segment was assessed for the quality of views and maintenance of gardens and verges. The road segments were also checked for local destinations that children can walk to. In total there were 60 items, as shown in Figure 3.1.

Infrastructure facilitating walking in local neighborhoods									
Features	Pedestrian amenities				Pedestrian safety		Streetscape aesthetics		Local Destinations
Elements	Walking Surface 0.25	Streets 0.20	Traffic control devices 0.25	Permeability 0.30	Personal 0.6	Traffic 0.6	Streetscape 0.55	Views 0.45	Facilities 1.0
Items	**Path type 0.25	**Number of lanes	Traffic signals 0.30	Walking lanes 0.5	***Path location 0.30	Zebra crossing 0.20	*Garden maintenance 0.25	Residential 0.22	Convenience store 0.30
	*Path slope 0.20		Speed hump 0.20	*Negotiability of pathways 0.5	Streetlights 0.20	Traffic signal crossing 0.20	**Verge maintenance 0.25	Commercial 0.22	Park, beach, playground, green space 0.20
	*Path material 0.15		Round-about 0.20		*Surveillance 0.20	Median refuge 0.15	*Street cleanliness 0.25	Water 0.14	Car park, train station, bus stop 0.10
	Path continuity 0.13		Kerb extension 0.10		Path obstacle 0.10	Round-about 0.15	**Trees verandas 0.20	Tended nature 0.14	Educational buildings 0.10
	*Path condition 0.10		Chicane 0.10		*Graffiti 0.10	Kerb extension 0.15	Outdoor seats 0.05	Semi-wilderness 0.14	Housing 0.10
	*Difficulty walking 0.07		Choker 0.10		*Vandalism 0.10	Pedestrian over/under pass 0.10		***Attractive streetscape 0.14	Service buildings 0.05
	Kerb mountable 0.05					Visible driveways 0.05			Other retail 0.05
	*Pram / wheelchair accessibility 0.05								Industrial buildings 0.05
									Offices 0.05

Figure 3.1. Neighborhood features, elements and items that facilitate walking near home in the SPACES street audit [226]

Numbers indicate weightings used to derive the four street-audit measures (features) in the present study. Asterisks indicate scoring of items: *0, 0.5 or 1; **0, 0.33, 0.66 or 1; ***0, 0.25, 0.5, 0.75 or 1. Items without asterisks were scored 0 or 1. Road-segment item scores are averaged and multiplied by item weightings into a mean neighborhood item score that are summed into a raw element score that is multiplied by the element weighting shown. Element-weighted scores are summed into the neighborhood feature score.

Each item in a given road segment was rated on a 0-1 scale for the presence or quality of the item. Examples: traffic signals was coded 0 (absent) or 1 (present), path slope was coded 0 (steep), 0.5 (medium) or 1 (level or flat), and number of lanes was coded 0 (>6 lanes), 0.33 (4-5 lanes), 0.66 (2-3 lanes), or 1 (1 lane). Mean road-segment scores were derived for each neighborhood then multiplied by item weightings and summed to derive element scores, which were further weighted and summed to derive four street-audit measures. The weightings suggested by the Delphi expert panel [226] were used to guide the weightings that were applied here. Features of the built environment were the focus of the present study, so Delphi expert panel [226] weightings for walking as recreation and for walking as transport were averaged.

Travel mode

Children's mode of transport to and from school was parent-reported in a travel log as either passive; car or bus, or active; walk, bicycle, skateboard or scooter.

Accelerometer

The water-resistant Actical accelerometer (Mini-Mitter Co., Inc., Bend, OR) with an omni-directional peizo-electric sensor that measures movements as step and accelerometer counts was used. Children's accelerations during jumping, running, fast and slow walking are respectively 2.5, 1.3, 0.5, 0.2 g [284] and involve rapid body movements of 1.75-3.5 Hz [271] . To differentiate children's habitual movements the Actical detects accelerations from 0.05-2.0 g at a sampling rate of 32 Hz. The monitor counts steps accumulated in preset sampling intervals 15, 30 or 60s by applying algorithms to the raw accelerometer signal on the vertical axis. Thirty second sampling intervals were used to allow at least 7 days of accelerometer and step data recording.

The simple step output from the accelerometer provides a reasonable approximation of daily walking and running, [196] which is analysed as step counts at light and moderate-vigorous intensities. The cut-points of 100 and 1500 counts·min^{-1} were used to differentiate sedentary vs light and light vs moderate-vigorous activity. The light to moderate-vigorous threshold corresponds approximately to an intensity of 3 MET derived in a study of children and adolescents wearing Actical accelerometers while they participated in a wide range of simulated and free-living activities [217]. (Higher thresholds have been derived for the Actical in other studies of young children and adolescents performing structured and unstructured activities [272, 285-286]).

Data reduction / cleaning

Actical Export File (Version 02.10) listings of accelerometer and step count data for each participant were read into and plotted within SAS (version 9.2; SAS Institute, Cary, NC) for checking. Researchers used event markers to log monitor delivery and collection times to allow non-participant data to be set to missing. SAS activity printouts were checked for excessive step or accelerometer counts accumulated during normal sleep 00:00-04:59 and once identified the accelerometer was considered faulty. Consequently, that day's data and all successive data were set to missing. Zero counts for more than 60 min were categorized as missing data (accelerometer not worn). The criterion for inclusion of activity data for each child was a minimum continuous worn time of 4 h because the analyses include hourly period of the day (06:00-22:00) and thereby adjust for missing periods. The inclusion criterion is less than the more usual 10 h for analysis of total daily activity [287] because the periods of interest (e.g., after school) are less than 10 h. School-term and holiday dates were used to assign school-day and holiday-day labels to each child's daily data. Children kept a daily travel log for a separate study of effects of travel mode on school-day activity; the logs revealed that children were absent from school for only 20 of 933 total child-days, and the data have not been adjusted for such absence.

Statistical analysis

Analyses of step counts were performed with the mixed model (ProcMixed) in the Statistical Analysis System (SAS version 9.2, SAS Institute, Inc, Cary, NC). Separate analyses were performed for total step counts per hour and for step counts per hour at light and at moderate-vigorous intensities. Raw step counts were used in all analyses, because log transformed counts showed greater non-uniformity of the residuals than non-transformed counts. The analyses were performed for chosen periods on school days and non-school days and for each of the three subgroups of children defined by age tertiles (a total of 18 separate analyses). Analyses for the tertiles were combined appropriately to give means, standard deviations, effects and their inferences for the children overall (thereby adjusting for age). The fixed effects in the mixed model included main effects to adjust for city (four levels), maximum daily ambient temperature (simple numeric), daily rainfall (two levels, presence or lack of rain), and gender (two levels, but some analyses were repeated separately for boys and girls). Hour of the day was also a nominal main effect with 17 levels (06:00 through 22:00), and each hourly observation was weighted by the number of recorded minutes; means and effects derived from the mixed model were thereby adjusted for missing and incomplete hourly recordings, when the child was not wearing the accelerometer. The predictors of interest in this study (the five GIS and four street-audit measures as nominal fixed effects ranked into tertiles) were each included in separate analyses with adult income and again with adult education included (as tertiles) to adjust for these potential confounders. Random effects were the child identity and the interaction of child identity with hourly period and with the child's numbered day of recording (1st, 2nd, etc.) to account for the levels of repeated measurement on each child. The random effect for child provided a standard deviation shown in tables and graphs representing true or stable differences between children over the monitoring period; this standard deviation represents an average of the between-child standard deviations in the age and predictor tertile groups (nine SD in total). Means and effects for activity during school-commuting were derived by limiting the analyses to the hours 08:00-08:59 plus 15:00-15:59 on school days; for analysis of activity after school the chosen hours were 16:00-17:59; finally for activity on weekend days and public holiday days the chosen hours were 09:00-17:59.

Generalized linear mixed modelling, realized with Proc Glimmix in SAS, was used to perform similar analyses for the time spent in the three activity intensities. The dependent variable was hourly observations of the number of each child's minutes in the given intensity. The logit link function and the binomial distribution were invoked to effectively specify logistic regression, and the fact that individual minutes spent at different intensities were not independent was taken into account by estimating an over-dispersion factor. The resulting distribution of the dependent variable is called pseudo-Bernoulli (see Example 38.1 in the Proc Glimmix documentation). The residual was specified in a manner that estimated the over-dispersion factor. Mean levels of activity were derived by back-transformation of the estimates from the logistic model. These estimates of activity are shown in the figures as minutes spent per hour at different intensities, but in tables the means and effects are shown as minutes per period (the hourly mean multiplied by the number of hours). The between-child standard deviation was an approximation derived from the random effect for child; values of the SD in figures and tables differ between tertiles of the predictor, because the computation of the SD from the logistic model depends on the value of the mean.

The inference about the true value of a given effect (a difference in means) was based on its uncertainty in relation to the smallest important difference, which was determined by standardization as 0.20 of the pure between-child standard deviation within the two compared subgroups [220]. (Assessment of magnitude of differences in time spent was performed with the means and SD of the logs of the odds of being active at a given intensity.) We used the mechanistic (non-clinical) version of such inference: the effect was deemed unclear if the uncertainty represented by the 90% confidence interval included smallest important positive and negative differences; the effect was otherwise deemed clear. Effects that were clear with the more conservative 99% confidence interval are also indicated, because for such effects there is less inflation of error arising from the large number of inferences in this study. For this reason, uncertainty in the estimate of each effect is also shown as a 99% confidence interval. The magnitude of a given clear effect was determined from its observed standardized value (the difference in means divided by the between-child standard deviation) using the following scale: <0.20, trivial; 0.20-0.59, small; 0.60-1.19, moderate; ≥1.20, large [220]).

RESULTS

Participant characteristics

A total of 226 children (51% female) provided 6.0 ± 1.8 d of valid data (mean ± SD; range 1-11 d), with an average daily worn time of 11.9 ± 2.0 h (range 4.0-20.5 h). The descriptive characteristics of the children are shown in Table 3.1. The ethnic proportions were European and other 72%, Polynesian 17%, and Asian 11%, which was reasonably representative of the population of NZ children (69%, 21% and 11% respectively) [288].

Table 3.1. Descriptive statistics in tertiles and for all children (n = 227).

	Tertile (range)			All children (mean ± SD)
	Lower	Middle	Upper	
Descriptive characteristics				
Age (y)	5.1-8.2	8.2-10.5	10.6-13.0	9.3 ± 2.1
BMI ($kg \cdot m^{-2}$)	12.6-16	16-18.5	18.5-40.5	18.2 ± 4.1
Income per adult[a] (NZ$10,000)	0.5-2.5	3.0-5.0	60-120	3.9 ± 2.0
Adult educational qualification[b]	1.0-2.0	3.0-4.0	5.0-5.0	3.6 ± 1.4
GIS measures				
School travel distance[c] (km)	0-0.9	0.9-2.1	2.1-16	2.1 ± 2.3
Recreational-amenity index[d]	0.8-1.1	1.2-1.7	1.8-4.9	1.7 ± 0.8
Food-outlet index[e]	0.0-1.1	1.4-1.9	2.1-4.4	1.6 ± 0.9
Walkability index[f]	4.0-17	18-21	22-35	19.5 ± 5.8
Dwelling density index[g]	1.0-4.0	5.0-7.0	8.0-10	5.9 ± 3.0
Street-audit measures				
Pedestrian safety index[h]	0.27-0.40	0.41-0.48	0.48-0.63	0.44 ± 0.08
Pedestrian amenities index[i]	0.32-0.50	0.51-0.62	0.64-0.75	0.55 ± 0.11
Streetscape aesthetics index[j]	0.57-0.63	0.64-0.66	0.68-0.79	0.66 ± 0.05
Local destinations index[k]	0.12-0.17	0.18-0.22	0.22-0.35	0.21 ± 0.05

[a]Income was calculated as household income per number of resident adults.
[b]Highest educational qualification; 1=primary school, 2=high school, 3=university entrance certificate, 4=diploma or trade certificate, 5= bachelor degree or higher.
[c]Distance from home to school was determined using GIS.
[d]Based on neighborhood green space, beaches or sport facilities present within 800 m of the population centroid [282].
[e]Based on eight types of food outlet (local convenience store, fast-food outlet, supermarket, etc.) present within 800 m of the population centroid [282].
[f]The sum of decile scores of retail area, road-intersection density, dwelling density and land-use mix [230, 282].
[g]Decile scores of dwelling density within 500 m of participant homes [282].
[h]Based on provision of safety infrastructure (pedestrian crossings, traffic lights, etc.).
[i]Based on provision of pedestrian facilities (footpaths, traffic calming devices, etc.).
[j]Based on subjectively ranked street; views, cleanliness and maintenance.
[k]Based on neighborhood places children can visit (schools, parks, playgrounds, etc.).

After adjustment for either of the two potential confounders, adult income and highest educational qualification, there was little difference in the effect of GIS and street-audit measures on children's physical activity. Therefore the unadjusted effects are presented here. The effects on steps children accumulated at light and moderate-vigorous intensity in the three periods when activity is potentially modified by the built environment are shown in Figure 3.2.

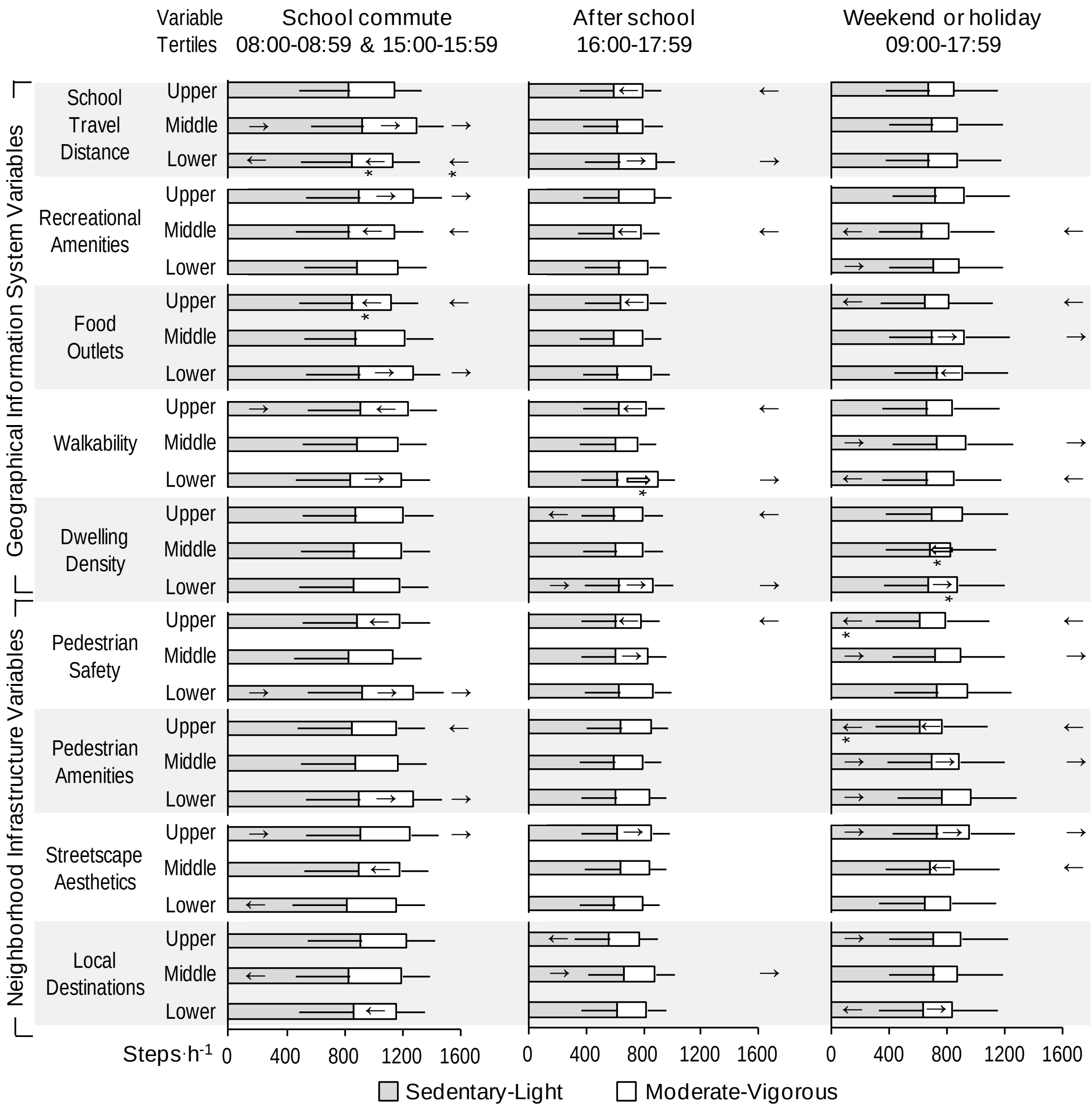


Figure 3.2. Effect of built environment variables on children's non-school hourly step counts (boys and girls combined) accrued at sedentary-light, and moderate-vigorous intensity.

Data are means; error bars are true standard deviations.

Arrows indicate substantial differences as follows: within the bar are inferences by intensity and to the right of the bar are the inferences for total steps. An arrow in an upper tertile indicates a substantial difference from the lower tertile; middle tertile arrows indicates a substantial difference between middle and upper and a lower tertile arrow indicates a substantial difference between lower and middle tertile. These differences are clear at the 90% level. Asterisks (*) indicate clear differences at the 99% level. Other differences were trivial or unclear. Size and direction of arrows indicate magnitude of the standardized difference, as follows: small increase →, small decrease ←, moderate increase ⇨, moderate decrease ⇦).

The effects on time children (boys and girls combined) spent in sedentary, light, and moderate-vigorous activity are shown in Figure 3.3. Data presented in Figure 3.2 and 3.3 shows the non-linear effects of built environment predictors however magnitudes of the effects on total steps and on moderate-vigorous minutes are difficult to interpret in these figures, so the data for these outcomes are summarized quantitatively in Tables 3.2 and 3.3 respectively.

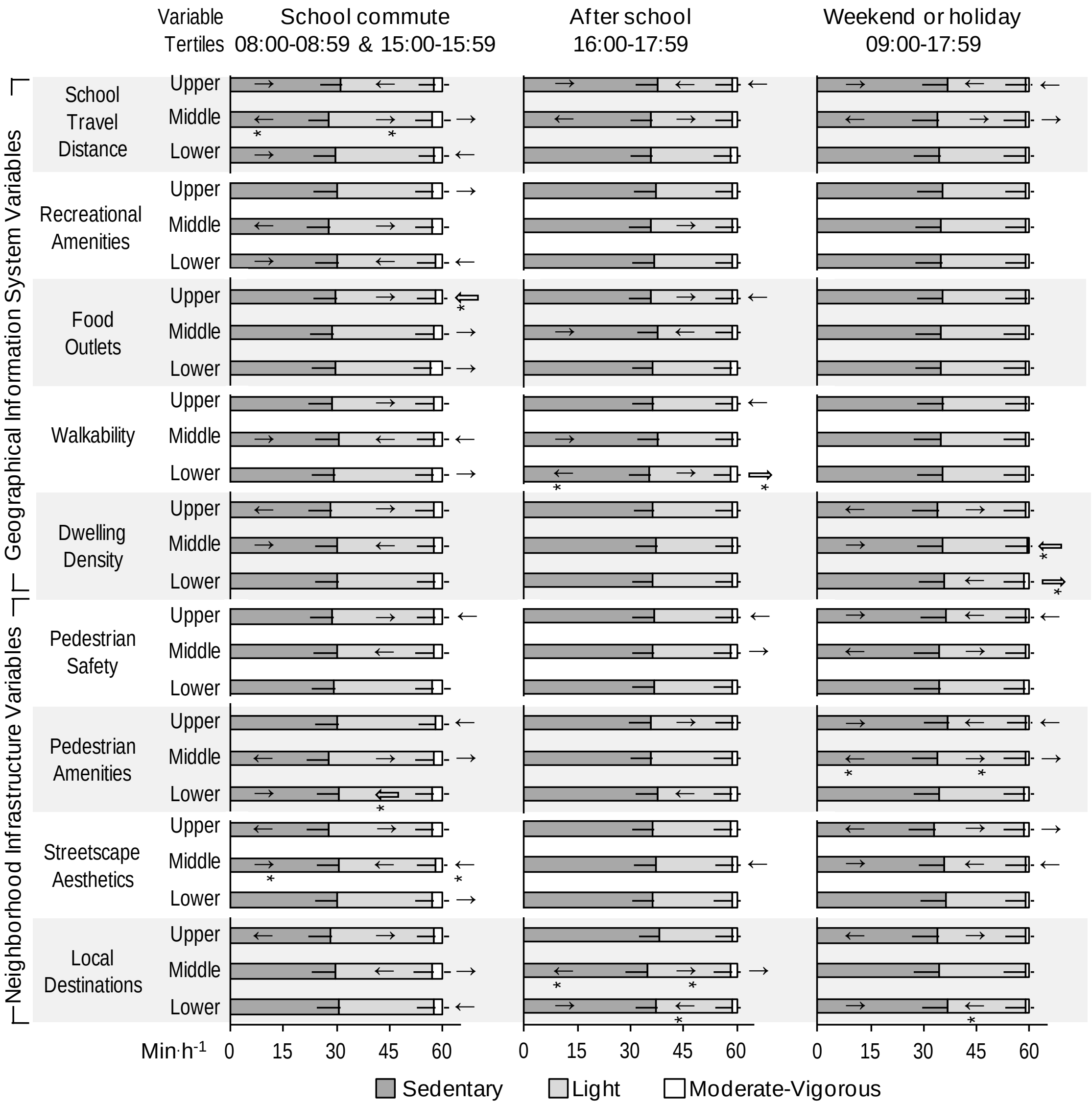


Figure 3.3. Effect of built environment variables on time children (boys and girls combined) spent in sedentary, light, and moderate-vigorous activity.

Data are means; error bars are true standard deviations.

Arrows indicate substantial differences as follows: within the bar are inferences for sedentary and light intensity and moderate-vigorous inferences are shown to the right. Arrows and asterisks indicate clear differences as described in Figure 3.2.

Table 3.2. Means and standard deviations of children's total steps per hour and total minutes of moderate-vigorous physical activity in time periods for children living in each tertile of GIS neighborhood variables listed in approximate order of the magnitude of the effects on physical activity.

	Total steps per hour			Moderate-vigorous total minutes (mean ± SD)		
	School commute[f]	After school[g]	Weekend / holiday day[h]	School commute	After school	Weekend / holiday day
School travel distance[a]						
Upper tertile	1140	↓790	850	4.8 ± 3.0	↓2.6 ± 1.6	↓9.0 ± 6.3
Middle tertile	↑1290	800	880	↑6.0 ± 3.8	2.6 ± 1.8	↑12.6 ± 8.1
Lower tertile	*↓1130	↑890	870	↓4.6 ± 2.8	3.0 ± 2.0	12.6 ± 8.1
SD[i]	440	310	370			
Recreational amenities[b]						
Upper tertile	↑1260	860	920	↑5.6 ± 3.4	2.8 ± 2.0	10.8 ± 7.2
Middle tertile	↓1140	↓780	↓820	5.6 ± 3.6	2.4 ± 1.6	10.8 ± 8.1
Lower tertile	1160	830	880	↓4.4 ± 2.8	2.8 ± 2.0	11.7 ± 8.1
SD	490	320	380			
Food outlets[c]						
Upper tertile	↓1110	830	↓810	*⇩4.2 ± 2.6	↓2.4 ± 1.6	9.9 ± 7.2
Middle tertile	↑1210	800	↑920	↑5.2 ± 3.0	2.6 ± 1.6	12.6 ± 9.0
Lower tertile	1260	850	910	↑6.6 ± 3.8	3.4 ± 2	10.8 ± 8.1
SD	480	320	380			`
Walkability[d]						
Upper tertile	1240	↓820	840	5.2 ± 3.4	↓2.6 ± 1.6	9.9 ± 7.2
Middle tertile	1160	760	↑930	↓4.6 ± 2.8	2.0 ± 1.4	11.7 ± 9.0
Lower tertile	1180	↑890	↓850	↑5.6 ± 3.6	*⇧3.4 ± 2.2	10.8 ± 8.1
SD	490	320	390			
Dwelling density[e]						
Upper tertile	1200	↓800	900	5.4 ± 3.4	2.8 ± 1.8	12.6 ± 8.1
Middle tertile	1190	800	830	5.0 ± 3.2	2.4 ± 1.6	*⇩8.1 ± 5.4
Lower tertile	1180	↑870	880	5.0 ± 3.2	3.0 ± 2.0	*⇧12.6 ± 8.1
SD	490	320	390			

An arrow in an upper tertile indicates a substantial difference from the lower tertile; middle tertile arrows indicate a substantial difference middle vs upper and a lower tertile arrow indicates a substantial difference of lower vs middle tertile. These differences are clear at the 90% level. Asterisks (*) indicate differences clear at the 99% level. Other differences were trivial or unclear. Size and direction of arrows indicate magnitude of the standardized difference, as follows: small increase ↑, small decrease ↓, moderate increase ⇧, moderate decrease ⇩).

[a]Distance from home to school was determined using GIS.

[b]Recreational amenities within 800 m of a neighborhood population-weighted centroid.

[c]Food outlets within 800 m of a neighborhood population-weighted centroid.

[d]Based on retail floor area, road intersection density, dwelling density and mixed land-use [230, 282].

[e]Dwelling density within 500 m of participant homes.

Table 3.3. Means and standard deviations of children's total steps per hour and minutes of moderate-vigorous physical activity for children living in each tertile of neighborhood street-audit variables.

	Total steps (h^{-1})			Moderate-vigorous activity (min ± SD)		
	School commute[e]	After school[f]	Weekend/ holiday day[g]	School commute	After school	Weekend / holiday day
Pedestrian safety[a]						
Upper tertile	1180	↓770	↓790	↓4.6 ± 3.0	↓2.0 ± 1.4	↓9.9 ± 7.2
Middle tertile	1130	830	↑890	5.2 ± 3.4	↑3.0 ± 2.0	10.8 ± 7.2
Lower tertile	↑1270	870	940	5.8 ± 3.8	3.0 ± 2.0	12.6 ± 9.0
SD[h]	480	320	380			
Pedestrian amenities[b]						
Upper tertile	↓1150	850	*↓770	↓4.4 ± 2.8	2.4 ± 1.6	↓9.0 ± 6.3
Middle tertile	1160	800	↑890	↑5.4 ± 3.4	2.8 ± 1.6	↑12.6 ± 8.1
Lower tertile	↑1260	840	960	5.6 ± 3.6	3.0 ± 2.0	12.6 ± 9.0
SD	480	320	380			
Streetscape aesthetics[c]						
Upper tertile	↑1250	860	↑960	5.8 ± 3.6	3.2 ± 2.0	↑13.5 ± 9.0
Middle tertile	1180	830	↓840	*↓4.2 ± 2.6	↓2.4 ± 1.6	↓9.0 ± 7.2
Lower tertile	1140	790	830	↑5.6 ± 3.4	2.8 ± 1.8	10.8 ± 7.2
SD	490	320	390			
Local destinations[d]						
Upper tertile	1220	760	900	4.8 ± 3.2	2.4 ± 1.6	10.8 ± 7.2
Middle tertile	1190	↑880	870	↑6.0 ± 3.8	↑3.2 ± 2.2	10.8 ± 7.2
Lower tertile	1150	820	830	↓4.6 ± 3.0	2.6 ± 1.8	11.7 ± 8.1
SD	480	320	390			

Arrows and asterisks (*) indicate clear differences as described in Table 2.
[a]Pedestrian safety infrastructure; streetlights, pedestrian crossings, traffic lights, etc.
[b]Pedestrian amenities; footpaths, speed humps, traffic calming devices, etc.
[c]Streetscape aesthetics: subjective assessment of street; views, cleanliness, and maintenance.
[d]Local destinations that children can visit (schools, parks, playgrounds, etc.).
[e]08:00-59 and 15:00-59, when children usually commute to and from school.
[f]16:00-17:59, when children can be active in their neighborhood during all seasons.
[g]09:00-17:59, when children can be active in the local neighborhood.
[h]True between-child standard deviation.

Effects of GIS variables in the figures and tables are summarized in Table 3.4, which show the tertile of each variable with the most substantial positive or negative effect on children's physical activity. During school commute times children living a medium distance from school were less sedentary and took more light, moderate-vigorous and total steps. After school children living closest to school participated in more step activity, while those farthest from school were the most sedentary and least active during non-school hours. Neighborhoods with the upper-tertile provision of recreational amenities had positive effects on children's step activity during all non-school hours. Children living in neighborhoods categorized as the middle tertile of recreational amenities spent the most time being active during non-school hours on school days.

There were negative effects on step activity in all three periods when children resided in neighbourhoods ranked the upper tertile for provision of food outlets. After school, neighborhoods characterized as the lower tertile of walkability had positive effects on total time children spent being active and on their moderate-vigorous and total steps. During the school commute times, children from neighborhoods of the middle tertile of walkability spent more time being sedentary and were the least active, but during non-school days these children took the most daily steps. The middle-tertile of dwelling-density had negative effects on time children spent in moderate-vigorous activity on non-school days.

The tertile of each street-audit variable with the most substantial positive or negative effect on children's physical activity is shown in Table 3.5. Children residing in neighborhoods ranked as the upper tertile of pedestrian safety spent less time in moderate-vigorous activity overall, and their step activity was least after school and during non-school days. There were positive effects on children's step activity during school commute times and on non-school days for children living in neighborhoods categorized as the lower tertile of pedestrian amenities. Children residing on roads graded into the upper tertile of attractive streetscapes had the highest step activity during all non-school hours. Residing in neighborhoods ranked as the middle tertile of local destinations had a positive effect on time children spent in moderate-vigorous activity during non-school hours on school days.

Table 3.4. Summary of clear substantial effects of GIS neighborhood variables on children's physical activity

	Activity Intensity			Step Activity		
	Sedentary	Light	Mod-vig	Light	Mod-vig	Total
School travel distance[a]						
School commute[f]	*↓ middle	*↑ middle	↑ middle	↑ middle	*↑ middle	*↑ middle
After school[g]	↑ upper	↓ upper	↑ lower	-	↑ lower	↑ lower
Weekend or holiday day[h]	↑ upper	↓ upper	↓ upper	-	-	-
Recreational amenities[b]						
School commute	↓ middle	↑ middle	↓ lower	-	↑ upper	↑ upper
After school	-	↑ middle	-	-	↓ middle	↓ middle
Weekend or holiday day	-	-	-	↓ middle	-	↓ middle
Food outlets[c]						
School commute	-	↑ upper	*⇩ upper	-	*↓ upper	↓ upper
After school	↑ middle	↑ upper	↓ upper	-	↑ lower	-
Weekend or holiday day	-	-	-	↓ upper	↑ middle	↓ upper
Walkability[d]						
School commute	↑ middle	↓ middle	↓ middle	↑ upper	↓ middle	-
Afterschool	*↓ lower	↑ lower	*⇧lower	-	*⇧lower	↑ lower
Weekend or holiday day	-	-	-	↑ middle	-	↑ middle
Dwelling density[e]						
School commute	↓ upper	↑ upper	-	-	-	-
After school	-	-	-	↑ lower	↑ lower	↑ lower
Weekend or holiday day	↓ upper	↓ lower	*⇩middle	-	*⇩middle	-

Clear substantial effects at 90% CL are shown for the tertile with the greatest positive or negative effect on children's activity with inferential comparisons as follows: 0.20-0.59 (small increase ↑, decrease ↓); 0.60-1.19 (moderate increase ⇧, decrease ⇩)[220]. Asterisks (*) are clear effects at 99% CL. Trivial or unclear effects are shown as (-).
Steps accumulated at <3 MET were defined as light and ≥3 MET as moderate-vigorous.
[a]Distance from home to school was determined using GIS.
[b]Recreational amenities within 800 m of a neighborhood population-weighted centroid.
[c]Food outlets within 800 m of a neighborhood population-weighted centroid.
[d]Based on retail floor area, road intersection density, dwelling density and mixed land-use [230, 282].
[e]Dwelling density within 500 m of participant homes.
[f]08:00-59 and 15:00-59, when children usually commute to and from school.
[g]16:00-17:59, when children can be active in their neighborhood during all seasons.
[h]09:00-17:59, when children can be active in the local neighborhood.

Table 3.5. Summary of clear substantial effects of neighborhood street-audit measures on children's physical activity

	Activity Intensity			Step Activity		
	Sedentary	Light	Mod-vig	Light	Mod-vig	Total
Pedestrian safety[a]						
School commute[e]	-	↑ upper	↓ upper	↑ lower	↑ lower	↑ lower
After school[f]	-	-	↓ upper	-	↓ upper	↓ upper
Weekend or holiday day[g]	↑ upper	↓ upper	↓ upper	*↓ upper	-	↓ upper
Pedestrian amenities[b]						
School commute	↓ middle	*⇧ middle	↓ upper	-	↑ lower	↑ lower
After school	-	↓ lower	-	-	-	-
Weekend or holiday day	*↓ upper	*↓ upper	↓ upper	*↓ upper	↓ upper	↓ upper
Streetscape aesthetics[c]						
School commute	*↓ upper	↑ upper	*↑ upper	↓ lower	↑ upper	↑ upper
After school	-	-	↑ upper	-	↑ upper	-
Weekend or holiday day	↓ upper	↑ upper	↑ upper	↑ upper	↑ upper	↑ upper
Local destinations[d]						
School commute	↓ lower	↑ upper	↑ middle	↑ upper	↑ middle	-
After school	*↓ middle	*↑ middle	↑ middle	↓ upper	-	↑ middle
Weekend or holiday day	↑ lower	*↓ lower	-	↓ lower	↑ lower	-

Clear substantial effects at 90% CL are shown for the tertile with the greatest positive or negative effect on children's activity with inferential comparisons as follows: 0.20-0.59 (small increase ↑, decrease ↓); 0.60-1.19 (moderate increase ⇧, decrease ⇩)[220]. Asterisks (*) are clear effects at 99% CL. Trivial or unclear effects are shown as (-).

Steps accumulated at <3 MET were defined as light and ≥3 MET as moderate-vigorous.

[a]Pedestrian safety infrastructure; streetlights, pedestrian crossings, traffic lights, etc.

[b]Pedestrian amenities; footpaths, speed humps, traffic calming devices, etc.

[c]Streetscape aesthetics: subjective assessment of street; views, cleanliness, and maintenance.

[d]Local destinations that children can visit (schools, parks, playgrounds, etc.).

[e]08:00-59 and 15:00-59, when children usually commute to and from school.

[f]16:00-17:59, when children can be active in their neighborhood during all seasons.

[g]09:00-17:59, when children can be active in the local neighborhood.

DISCUSSION

It is generally accepted that neighbourhood play [249, 280] and active commuting are important contributors to children's daily steps and moderate-vigorous activity [238, 268]. The urban environment near children's residence with its blend of retail and commercial facilities, traffic volumes, pedestrian infrastructure and nearby parks, schools or shops either constrain or encourage independent mobility and play. Determining which urban features modify children's activity can inform best practice in designing active residential environments [289]. Most urban-environment features reported here appeared to have incongruous effects on children's non-school hour physical activity. The dissimilar effects can be rationalized by classifying urban features as those that either provided safe opportunities for additional active commuting or play and those that constrained activity owing to safety concerns.

During school-travel times children accumulated more daily steps (presumably through walking) when they resided a reasonable distance from school, on safe attractive streets, with accessible green space or where there were few pedestrian facilities. In previous studies it was also found that children's activity was higher in environment's that permitted safe walking either to school [238, 265] or on inner-city streets [250] and in two studies [238, 250] walking was verified by satellite-tracking. Late afternoon on school days and during non-school days the most active children resided in neighborhoods characterized as low-mid walkable, with aesthetically pleasant streets, near few food outlets or less pedestrian infrastructure. This would suggest that less urbanized areas are more walkable for children and that high walkability based on adult indicators of greater street connectivity, mixed land-use, dwelling density and retail areas [282] might be inappropriate for children. There were negative effects on children's daily moderate-vigorous activity for children residing farther from school in this and another study [259] presumably because of the limited opportunity to walk to school. This notion is supported by the fact that during holidays or weekends, school distance had no clear effect on step activity. High walkability had positive effects on adolescent moderate-vigorous activity [259], which suggest that walkability for younger children may not be comparable with walkability indexes for adolescents and adults. Further research using satellite-tracking to test different child-walkability scales is required to derive an appropriate walkability index for children.

Late afternoon on school days the most active children resided in neighborhoods more conducive for safe play, which were defined as low-density housing areas, close to school, or those with nearby green space, beaches or sports grounds. Other research has also identified several contributors to higher levels of activity through increased play opportunities [280-281] including extra yard space per dwelling for outdoor play that is typical of low-density housing. This assertion, that providing safe play areas is important to daily activity have been confirmed in studies that used satellite-tracking to identify that schools [250, 266], parks, grassland, woodlands, beaches and other green space [233, 249, 266, 268] are important settings for children's moderate-vigorous activity. In contrast, children in this study on non-school days were less active when they resided in medium-density housing with less yard space for play or where there was less nearby green space areas intended for play.

Parental concerns about high traffic volumes may have contributed to our finding that more pedestrian amenities and pedestrian safety infrastructure were correlated with clear substantial negative effects on children's steps and moderate-vigorous activity during non-school hours. Previous research reported that good quality sidewalks [253] and additional road safety elements were associated with increased physical activity in adolescents [244]. It has also been advocated that reengineering roads with pedestrian crossings lights, chicanes and speed humps reduced child pedestrian injuries and create pedestrian friendly environments [290-291]. The effects of additional traffic safety infrastructure reported here are more consistent with other findings, which attribute lower daily activity to parental concerns about child traffic-safety [257]. Apparently, more traffic infrastructure is an indicator of higher traffic volume, which has to be low before parents allow children to roam independently in less urbanized streets [249].

Children residing near busy arterial roads with more pedestrian safety infrastructure have increased risk of pedestrian-vehicular collisions [290] conversely streets with less pedestrian amenities have minimal traffic flows and reduced risk of pedestrian-vehicular collisions [116, 276]. Young children have additional safety-risk navigating vehicular traffic [278-279, 292] associated with undeveloped visual or impaired motion processing skills that let children perceive moving traffic as motionless [293]. To keep children safe many parents chauffeur children, which has reduced pedestrian-vehicular death (15%) and injury (31%) as a proportion of the total rate [294]. Unfortunately, chauffeuring has increased time children spend in cars [115] and consequently increased the proportion of death (85%) and injury (69%) resulting from vehicle-vehicle crashes [294]. Road design affects pedestrian safety with low connectivity cul-de-sac and curvilinear networks increasing injury severity in vehicle-pedestrian collisions whereas high connectivity streets lowered pedestrian injury risk and increased passenger injuries in vehicle-vehicle crashes [295]. The challenge for urban designers is to construct road environments that improve safety for children making journeys as either pedestrian's or passengers.

There was also a negative effect on children's activity when more food outlets were present in neighborhoods, which is consistent with recent research on adolescents [240].

Most food outlets are located in shopping centres, which owing to safety concerns may prompt parental constrain on children's independent mobility thereby reducing daily activity [292].

When the priority is to engineer active urban communities parents first need assurance that children will be safe when roaming and playing independently by providing safe routes to neighborhood places [292]. Urban planners have been investigating safer street designs that use in-pavement pedestrian crossing light systems [296] and non-traffic walkways that link cul-de-sacs, parks, schools and shopping centre's [297]. Incorporating pedestrian safety and walkable neighborhood design principles into Smart Growth residential communities increased children's independent mobility near home [298]. In established neighborhoods children's independent roaming and play may benefit by reducing traffic flow and increasing pedestrian safety with self-explaining roads, school drop off zones, non-skid road surfacing, landscaping and lane narrowing [297]. Further investigation is required to determine if traffic calming and redesign of neighbourhoods will increase children's habitual physical activity.

Strength and limitations

There are a number of strengths in the current study; including examination of multiple neighborhoods measured using a large number of objectively assessed built-environmental variables to determine effects on activity using standardized magnitudes. The sample size was sufficient to determine some effects with 99% confidence limits. The inclusion of accelerometer step-counts is also novel and data were collected across all seasons including holidays. The cross-sectional nature of this study and not collecting objective activity-location data meant that causal inferences about urban characteristics and children's physical activity could not be made.

CONCLUSIONS

The built environment had clear substantial positive effects on children's physical activity. Children's non-school hour activity decreased in more urbanised neighborhoods near commercial centres, with higher traffic danger or less play space. Urban planners and developers need to design for safe neighborhood play spaces with traffic-free or traffic-reduced pedestrian networks designed to drastically lower vehicle-pedestrian collisions so that children can actively commute and play independently.

Acknowledgements

This work was developed through the Understanding Relationships Between Neighbourhoods and Physical Activity (URBAN) study, funded by the Health Research Council (HRC) of New Zealand [grant number: 07/356], and the Neighbourhoods and Health project, supported by the [grant: 08/048]. The funding bodies were not involved in the design, conduct, data collection, management, or publication of the study. The authors also gratefully acknowledge the participants who completed the study, research assistants who collected the data and the territorial authorities for providing the GIS datasets.

CHAPTER 4: CHILDREN'S STEP COUNTS AT LIGHT AND MODERATE-VIGOROUS INTENSITIES DURING SCHOOL AND NON-SCHOOL DAYS

This chapter comprises the following paper submitted to American Journal of Preventive Medicine: McGrath, L. J., Hinckson, E. A., & Hopkins, W. G. (2013). *Manuscript submitted for publication.*

ABSTRACT

Background: Pedometer step counts provide estimates of total daily activity, but pedometers do not record intensity. Children's step counts provided by accelerometers to determine the daily pattern of steps at light and moderate-vigorous intensities were analysed. **Methods:** Children (n= 308; 52% girls; age 9.3 ± 2.5 y, mean ± SD) from four geographically separate cities participated in the Understanding Relationships between Activity and Neighborhoods (URBAN) study and provided up to seven days of Actical accelerometer data. Hourly step counts (total, and at light and moderate-vigorous intensities defined by a ~3-MET threshold) were analysed with mixed modelling. **Results:** Steps at moderate-vigorous intensity were accumulated at a mean cadence of ~80 step counts·min^{-1} and accounted for a quarter of school-day total steps (12,700 ± 4,200) and a fifth of holiday-day steps (12,600 ± 5,900). More girls than boys met their daily step recommendations on school days (44% vs 33%) and holiday days (31% vs 22%). On school-days girls from the upper body-mass index tertile were most active, but differences between boys' body-mass index tertiles were unclear. During holiday days Polynesian children took 2,100 less steps than non-Polynesians. Onset of evening darkness, days colder by 10 ºC, and daily rainfall ≥1 mm, respectively accounted for small-large, small, and trivial-small decreases in step activity. **Conclusions:** Promotion of outdoor and indoor active play is needed to offset lower step activity that occurs during unfavorable environmental conditions or holiday days, when children have more freedom to self-select activities.

INTRODUCTION

Habitual physical activity contributes to psychological, musculoskeletal and cardiovascular health in children [8]. Children's activity is influenced by many factors and may be assessed as daily step totals or the proportions of activity at given intensities. It is generally accepted that boys accumulate more daily steps than girls [299]. Previous research has determined that children's volume and intensity of activity is affected by time of day, school vs holiday or weekend days, season, rainfall and ambient temperature [139, 300-301]. Children in the healthy range of body-mass index may also accrue higher daily step counts [218]. In contradiction to this norm Polynesian children that have a higher prevalence of obesity are more active at moderate-vigorous intensity than non-Polynesian children [302].

Although there have been numerous studies of children's habitual physical activity, a recent review highlighted the need for more research to accumulate normative data, especially in relation to children's daily step counts and the intensity of their activity [196]. Step counts are quantified objectively with either pedometers or accelerometers. Researchers often prefer pedometers, which are simple to use, affordable, and give a reasonable approximation of children's physical activity volume [236-237]. Most pedometers accumulate step counts without regard to time of day or intensity, which makes it impossible to determine children's daily step activity patterns or the proportion meeting moderate-vigorous activity guidelines. The intensity of free-living activity is usually quantified with accelerometers, which also provide better estimates of energy expenditure than daily pedometer steps or self-reported physical activity [303]. Some accelerometers offer the advantage of recording step counts at defined intensities throughout the day.

The purpose of this study was to determine the proportion of steps New Zealand children accumulate at light and moderate-vigorous intensities using the Actical step-count accelerometer. In addition, factors that affect day-to-day variation in New Zealand's children's step activity during school and non-school days were investigated. Children's adherence to step-count guidelines [218] and the effect of rainfall, onset of evening darkness, ambient temperature, age, ethnicity and body-mass index on children's step activity were also examined.

METHODS

Participants

Trained interviewers recruited participants door to-door in the Understanding the Relationship between Activity and Neighbourhoods (URBAN) cross-sectional study, which has been previously described in detail [206]. Children (n= 819) were eligible for recruitment only when an adult (n= 538) from the same household joined the URBAN study. Adults (n= 308) provided informed consent and children (one per household) between ages of 5 and 12 y inclusive (at the time of recruitment) assented to participate in the study. Geographical Information System protocols [230] were used to randomly select 2032 households from 48 neighbourhoods, within four diverse New Zealand cities. Twelve neighbourhoods per city were purposefully selected to represent four residential compositions; high and low walkability combined with high and low density of Māori and Pacific Island (Polynesian) populations. Polynesian children have elevated health risk [13] owing to exceptionally high obesity rates that are 4-5 times that of other ethnicities [302]. The proportions of European or other, Polynesian and Asian ethnicities in the data analyzed were 75%, 16% and 9% respectively. The corresponding proportions of children in the New Zealand population are 70%, 21% and 9% [288].

Instruments

Accelerometer

Children wore the water-resistant Actical step-count accelerometer (Mini-Mitter, Bend, OR) attached to an elastic waistband and positioned on the left hip. The omni-directional peizo-electric sensor detects accelerations in the 0.05-2.0 g range at a sampling rate of 32 Hz. The motion sensor measures children's typical body movements (1.75-3.5 Hz) [271], jumping, running, fast and slow walking (respectively 2.5, 1.3, 0.5, 0.2 g) [284] as accelerometer counts per sampling interval or epoch. The monitor applies algorithms to the output signal of the vertical axis to calculate steps accumulated in preset sampling intervals. The Actical accurately registered step counts·min^{-1} (99.2%) when compared with video-recorded steps during treadmill walking at 83 m·min^{-1} and running at 133 m·min^{-1} but step counts during slow walking at 50 m·min^{-1} were underestimated (92.6% accurate) [304]. Sampling intervals of 30 s were selected to allow 7-11 days of step and accelerometer counts to be recorded. To differentiate step counts at light and moderate-vigorous intensities we chose a cut-point of 1500 counts·min^{-1}, which corresponds approximately to an intensity of 3 MET derived in a study of children and adolescents wearing Actical accelerometers while they participated in a wide range of simulated and free-living activities [217]. (Higher thresholds have been derived for the Actical in other studies of young children and adolescents performing structured and unstructured activities [272, 285-286]).

Data reduction

Actical Export File (Version 02.10) listings of accelerometer and step count data for each participant were read into and plotted within SAS (version 9.2; SAS Institute, Cary, NC) for checking. Researchers used event markers to log monitor delivery and collection times to allow non-participant data to be set to missing. SAS activity printouts were checked for excessive step or accelerometer counts accumulated during normal sleep 00:00-04:59 and once identified the accelerometer was considered faulty. Consequently, that day’s data and all successive data were set to missing. Zero counts for more than 60 min were categorized as missing data (accelerometer not worn). Our criterion for inclusion of activity data for each child was a minimum continuous worn time of 4 h because our analyses include hourly period of the day (06:00-22:00) and thereby adjust for missing periods. The inclusion criterion is less than the more usual 10 h for analysis of daily activity [287] because the periods of interest (e.g., after school) are less than 10 h. School-term and holiday dates were used to assign school-day and holiday-day labels to each child's daily data. Children kept a daily travel log for a separate study of effects of travel mode on school-day activity; the logs revealed that children were absent from school for only 20 of 933 total child-days, and the data have not been adjusted for such absence.

Meteorological data

Children participating in the study resided in four geographically separate cities where climatic conditions ranged from cool alpine to warm sub-tropical. The location, mean monthly rainfall and daily minimum and maximum temperatures from historical records for each city were respectively; North Shore (36º48’S, 174º45’E, 65-145 mm, 7–16 ºC, 14–24 ºC), Waitakere (36º55’S, 174º39’E, 65-145 mm, 7–16 ºC, 14–24 ºC), Wellington (41º17’S, 174º46’E, 60-150 mm, 6–13 ºC, 11–21 ºC) and Christchurch (43º32’S, 172º37’E, 40-80 mm, 2–12 ºC, 11–23 ºC). New Zealand’s Meteorological Service selected a weather station within the boundary of each city and provided daily minimum and maximum ambient temperatures (ºC), and daily rainfall (mm) totals for the data collection period. The onset of darkness was established as the commencement of evening twilight after sunset (provided by the meteorological service). We adopted the

New Zealand Meteorological Service definition of a wet day as a day with >1 mm of rainfall. Daylight saving extends the onset of evening darkness by one hour during Spring, Summer and Autumn providing increased opportunity for children's outdoor play. We do not present data for morning daylight effects because only 25% of children were wearing the monitor 06:00-07:00. Accelerometers were worn by 95% of children at 20:00 and 85% at 21:00.

Statistical analysis

All statistical analyses were performed with the mixed model (ProcMixed) in the Statistical Analysis System (SAS version 9.2, SAS Institute, Inc, Cary, NC). Separate analyses were performed for total step counts and for step counts at light and at moderate-vigorous intensities; these analyses were performed for school days and non-school days and for each of the three subgroups of children defined by age tertiles (a total of 18 separate analyses). Analyses for the tertiles were combined appropriately to give means, standard deviations, effects and their inferences for the children overall.

The fixed effects in the mixed model included main effects to adjust for city (four levels), maximum daily ambient temperature (simple numeric), daily rainfall (two levels, presence or lack of rain), and gender (two levels, but some separate analyses were repeated for boys and girls). Hour of the day was also a nominal main effect with 17 levels (06:00 through 22:00).

The effect of ambient temperature on step count was expressed as the effect of a 10 °C decrease. The standard deviation of the daily maximum temperature within each city ranged from ~3 to ~5 °C, so the effect of a 10 °C difference is a little more than twice the standard deviation, which is the appropriate difference for evaluation of the effect of a numeric linear predictor [220]. The effect of daily rainfall on step count was modelled and assessed simply as the presence (≥1 mm) or lack of rainfall (<1 mm), because rainfall had a markedly skewed distribution. Inclusion of rainfall in this form in the model effectively adjusted the mean step counts to 50% rainy days.

The effect of evening twilight and darkness on mid-evening activity was estimated in a separate analysis by inclusion of a main-effect numeric variable with a value equal to the proportion of the hour falling after sunset for periods 17:00 through 20:00 inclusive and a value of zero for all other periods. Analyses were also performed with an additional fixed effect for either body-mass index (as tertiles) or ethnicity (three levels: European and other, Polynesian, Asian).

Random effects were the child identity and the interaction of child identity with hourly period and with the child's numbered day of recording (1st, 2nd, etc.) to account for the levels of repeated measurement on each child. The random effect for child provided a standard deviation shown in tables and graphs representing stable differences between children over the monitoring period. Raw step counts were used in all analyses, because log transformed counts showed greater non-uniformity of the residuals than non-transformed counts. Mean levels of activity and effects on activity are shown as steps per hour or steps per day (the hourly mean multiplied by 17); these means and effects were derived from the mixed model as estimates that were adjusted for missing values of step counts in any hourly periods when the child was not wearing the accelerometer.

The inference about the true value a given effect (a difference in means) was based on its uncertainty in relation to the smallest important difference, which was determined by standardization as 0.20 of the pure between-child standard deviation within the two compared subgroups [220]. We used the mechanistic version of such inference: the effect was deemed unclear if the uncertainty represented by the 90% confidence interval included smallest important positive and negative differences; the effect was otherwise deemed clear. Effects that were clear with the more conservative 99% confidence interval are also indicated, because for such effects there is less inflation of error arising from the large number of inferences in this study. For this reason, uncertainty in the estimate of each effect is also shown as a 99% confidence interval. The magnitude of a given clear effect was determined from its observed standardized value (the difference in means divided by the between-child standard deviation) using the following scale: <0.20, trivial; 0.20-0.59, small; 0.60-1.19, moderate; ≥1.20, large [220].

RESULTS

Participant characteristics

A total of 219 children (51% females) provided 6.0 ± 1.8 d of valid data (mean ± SD; range 1-11 d); of these, two children provided one day, eight provided two days, and 15 provided three days of data. Daily total worn time after averaging for each child was 11.9 ± 2.0 h (mean ± between-child SD; range 4.0-20.5 h).

The hourly total step counts for the females and males for holiday days and school days are shown in Figure 4.1. It is evident that children in this study took the most steps on school days during travel times and the lunch hour, and the average child exceeded the recommended step count·h^{-1} (recommended daily steps [218] divided by 17) during the middle part of the day on school and holiday days.

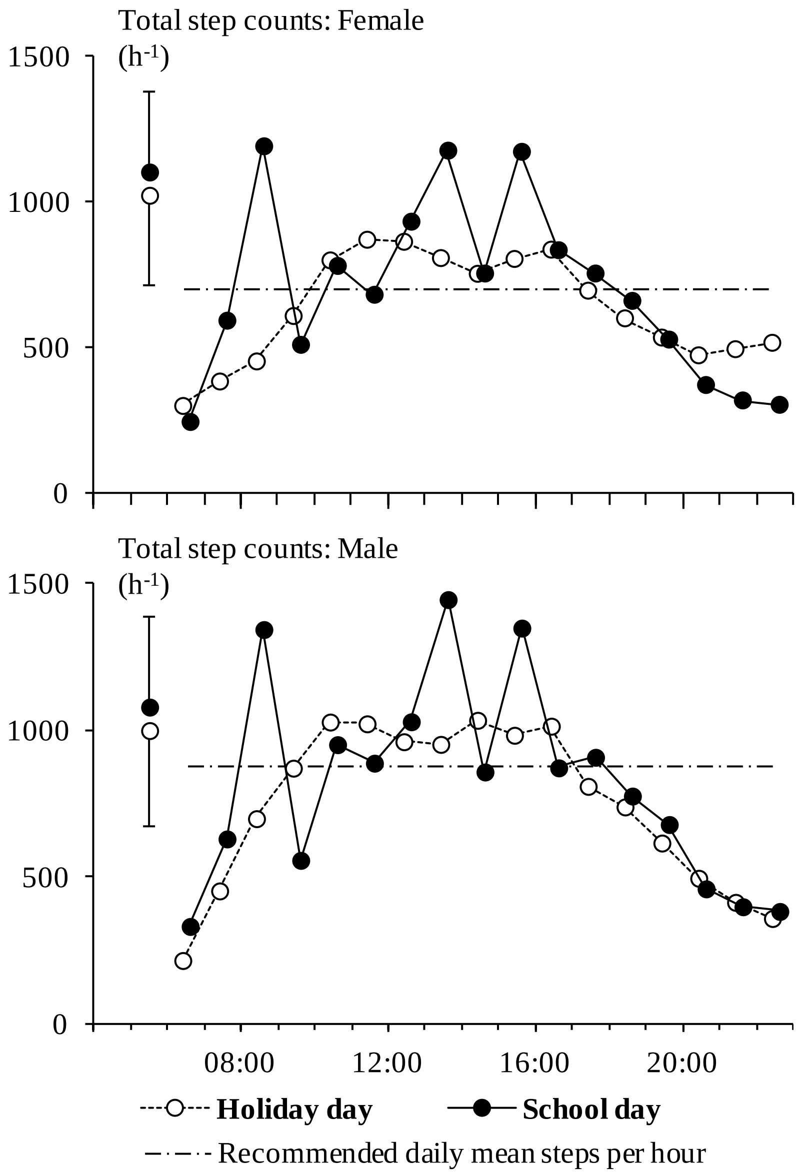


Figure 4.1. Total step counts for female and male children for each hour of school days and holiday days.

Data are means; error bars are SD. The dashed lines are recommended daily steps [218] of 12,000 and 15,000 for female and male children respectively divided by 17 (the number of analyzed hourly periods).

Table 4.1 shows the proportions of children meeting daily recommended step counts for each age tertile and for all children. More children exceeded the daily step-count recommendation (12,000 girls, 15,000 boys) [218] on school days than on holiday days in each of the three age tertiles. On holiday days the proportion of girls meeting the step guidelines decreased with increasing age, whereas there was little effect of age tertile on guideline adherence on school days. Boys in the mid-age tertile had the highest step guideline adherence on school and holiday days, but there was little difference between the lower and upper age tertiles.

Table 4.1. Daily step activity in the age tertiles and for all children (n = 219).

	Age tertile			
	Lower	Middle	Upper	All children
Age range (y)	5.1-8.1	8.2-10.5	10.6-13.0	5.1-13.0
Children meeting daily total step guidelines[a] (%)				
Females holiday day	53	30	11	31
Females school day	43	44	44	44
Males holiday day	21	26	18	22
Males school day	32	37	31	33
Holiday-day steps per day (mean ± SD)				
Light	10300 ± 4800*	9400 ± 4500*	8100 ± 3400**	9300 ± 4400
Moderate-vigorous	2300 ± 1700	2500 ± 1500	2100 ± 1600	2300 ± 1600
Total	12600 ± 5900	11900 ± 5300*	10300 ± 4300**	11600 ± 5300
School-day steps per day (mean ± SD)				
Light	9700 ± 3900	9400 ± 4200	9700 ± 4200	9600 ± 4100
Moderate-vigorous	3000 ± 1700	3400 ± 2000	3100 ± 1600	3200 ± 1800
Total	12700 ± 4200	12700 ± 5400	12900 ± 5200	12800 ± 5000

Steps accumulated at <3 MET were defined as light and ≥3 MET as moderate-vigorous.
[a]12,000 and 15,000 steps per day for girls and boys respectively [218].
Asterisks in lower, middle and upper age tertiles indicate inferential comparisons of lower with middle, middle with upper, and upper with lower tertiles respectively as follows: clear substantial difference at the *90% and **99% level. All other differences were unclear.

Also shown in Table 4.1 are the children's daily mean step counts and between-child standard deviations in each age tertile and for all children. The smallest important differences in daily step counts (0.20 of the SD) for all ages were ~900 for light steps, ~300 for moderate-vigorous steps, and ~1000 for total steps. The clear differences in children’s light steps and total steps between age tertiles indicate substantially less activity amongst older children on holiday days. There was little effect of age tertile on activity during school days, but the differences were unclear.

The daily step counts summarized in Table 4.1 are shown separately for females and males in Figure 4.2, from which it is apparent that girls rather than boys generally showed a reduction in activity with increasing age on holiday days: differences between younger and older girls were clear at the 99% level for light-intensity daily steps (-3200, ±3400; mean, ±99% confidence limits) and total daily steps (-4200; ±4100). Moderate-vigorous activity on school days also showed the possibility of a reduction with age for girls but an increase with age for boys. Total steps showed little effect of age on school days for either sex, but the effects were unclear.

It is also apparent from Figure 4.2 that boys were generally more active than girls at all intensities, especially amongst the older children. The differences between the sexes for the combined age groups were clear at the 99% level for light-intensity steps on holiday days (1700, ±1800), for moderate-vigorous steps on holiday days (870, ±820) and school days (1100, ±850), and for total steps on holiday days (2600, ±2200) and school days (2100, ±2100). When expressed as steps per min, there were only trivial differences between girls and boys on holiday days at light intensity, moderate-vigorous intensity and overall: values (mean ± SD) for girls were respectively 11 ± 6, 80 ± 25, and 13 ± 6, while those for boys were 12 ± 6, 80 ± 16, 15 ± 8. However, on school days, boys showed small increases in step intensity (13 ± 6, 82 ± 14, 16 ± 7) compared with girls (11 ± 5, 80 ± 14, 14 ± 5).

There was little effect of ethnicity on step counts during school days, but on holiday days total step counts for Polynesian children (9900 ± 5200, mean ± SD) were substantially less than those for European or other (12000 ± 5200) and for Asian children (12100 ± 5200). These differences were small but clear only at the 90% level.

To determine the effect of body-mass index ($kg \cdot m^{-2}$) on step activity children were grouped into tertiles: low (14.4 ± 1.3; mean ± SD), middle (17.3 ± 1.6) and upper (22.4 ± 4.8). Differences in mean daily step counts by body-mass index and gender groups are shown in Figure 4.3. During holiday days girls from the mid-BMI tertile performed less total steps than girls from the lower (-1,100, ±2,900; mean, ±99% confidence limits) and upper-BMI tertiles (-1,300, ±2,900). Boys from the mid-BMI tertile also completed (-2,600, ±4,400) less daily steps during holidays than boys from the low-BMI tertile. Girls with higher BMI generally showed an increase in daily steps on school days with the mid (-1,300, ±2,700) and lower BMI tertiles (-1,600, ±2,700) performing less daily steps than upper-BMI tertile girls. We ranked each gender-age tertile into BMI tertiles and found similar differences in mean daily steps as those established for all children, but effects were mostly unclear.

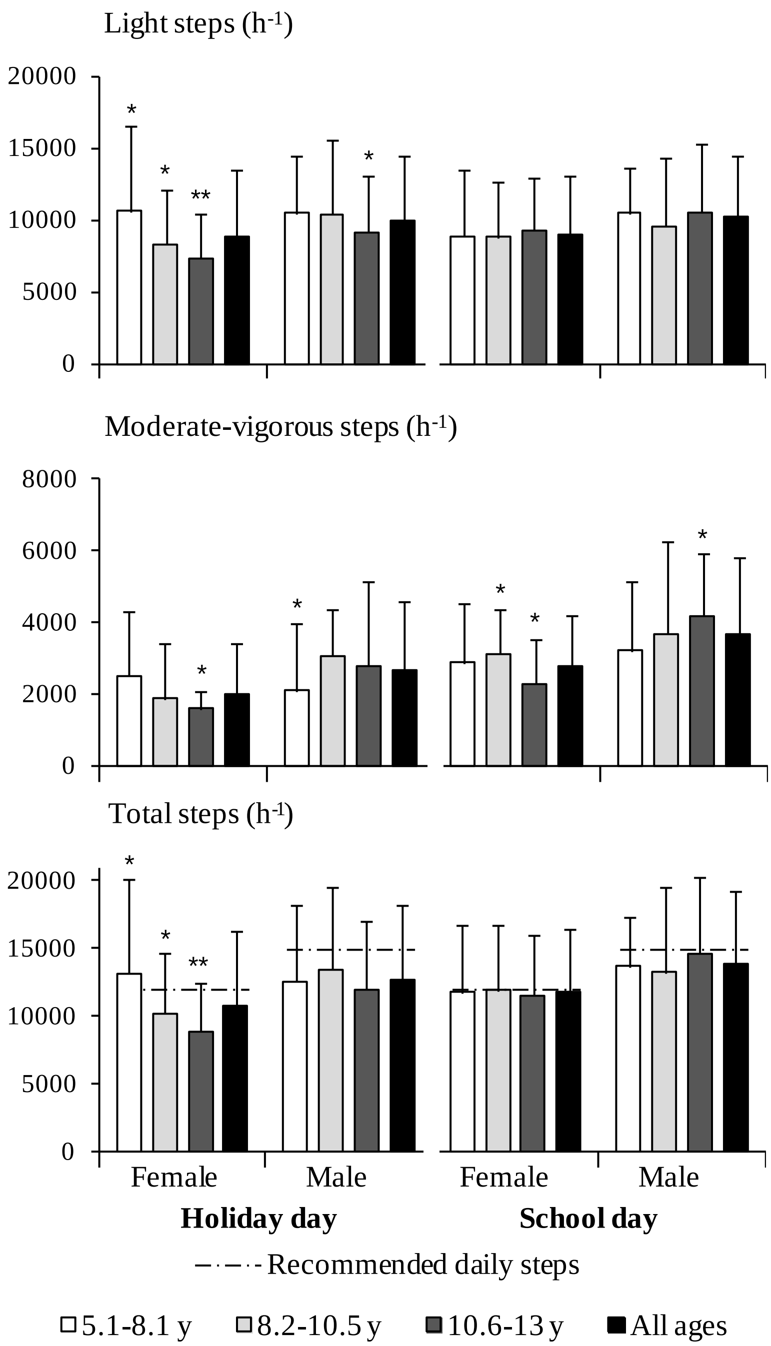


Figure 4.2. Daily steps on school and holiday days for female and male children by activity intensities and age tertiles.

Data are means; error bars are SD. Asterisks in lower, middle and upper age tertiles indicate inferential comparisons of lower with middle, middle with upper, and upper with lower tertiles respectively as follows: clear substantial difference at the *90% and **99% level.

All other differences are unclear. For comparisons of females with males, see text.

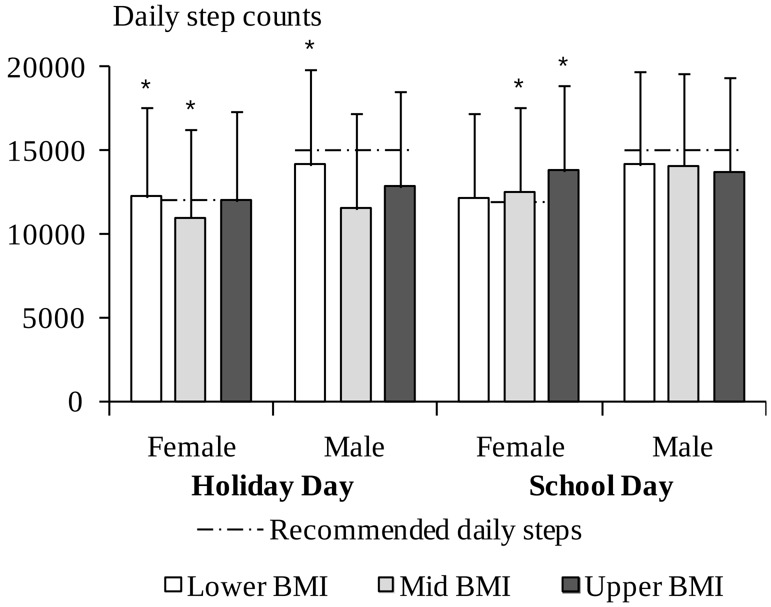


Figure 4.3. School and holiday day steps (06:00-22:59) for all children by body-mass index (BMI) tertiles.

Data are means; error bars are SD. Asterisks in lower, middle and upper BMI tertiles indicate clear substantial differences at the 90% level for lower vs middle, middle vs upper and upper vs lower tertiles respectively.

All other differences were unclear.

Descriptions of meteorological variables in the four cities during the data collection period are shown in Table 4.2, and the effect of meteorological variables on children's step activity is shown in Table 4.3. There were small to moderate clear substantial negative effects on light-intensity and total steps associated with the onset of evening darkness. The negative effects of onset of evening darkness on moderate-vigorous steps were large during holiday days and moderate on school days. On days colder by 10 °C step counts at all intensities decreased during school days; the changes were substantial and small except for a trivial effect on moderate-vigorous steps. There were trivial or unclear negative effects of wet days on all step activity except for a small substantial negative effect on moderate-vigorous steps on school days.

Table 4.2. Meteorological variables in the four cities.

	North Shore	Waitakere	Wellington	Christchurch
Sunset mid-winter	17:40	17:40	17:30	17:31
Sunset mid-summer	21:14	21:14	21:31	21:49
Max temperature (°C) (mean ± SD)	14.2 ± 2.6	13.6 ± 3.5	13.4 ± 3.5	11.9 ± 4.4
Wet day[a] (%)	50	59	38	37

[a]Days with rainfall >1 mm.

Table 4.3. Effect of weather and sunset on children's hourly steps.

	Sedentary-light	Moderate-vigorous	Total
Darkness[a]			
holiday day	-37; ±95*	-148; ±75**	-190; ±140**
school day	-84; ±67**	-108; ±58**	-200; ±100**
Colder day[b]			
holiday day	-80; ±100**	-27; ±61*	-140; ±140**
school day	-80; ±52**	-4; ±40⁰	-88; ±76**
Wet day[c]			
holiday day	-34; ±67⁰⁰	-13; ±47	-40; ±96⁰⁰
school day	-27; ±31⁰⁰	-32; ±25**	-56; ±45⁰⁰

Data are mean and 99% confidence limits.
Smallest important effects for hourly steps (0.20 of between-child SD): light, 50; moderate-vigorous, 20; total, 60.
Clear substantial effect at the *90% and **99% level.
Clear trivial effect at the ⁰90% and ⁰⁰99% level.
[a]Change in step count after sunset between 17:00 and 20:59.
[b]Change in step count for a 10 °C fall in temperature.
[c]Change in step count for days with rainfall >1 mm.

DISCUSSION

In this study we investigated the daily steps children accumulated while living in a variety of socioeconomic and ethnically diverse urban neighborhoods in climatic conditions that varied by location and season. Children's step activity was greatest during playtime and travel to and from school. From early morning onwards the average-child's step activity increased steadily with a sustained period of high activity from mid-morning till late afternoon followed by a gradual decline in activity towards nighttime. Girls took fewer steps than boys at all intensities and the differences were clear and substantial. Our results indicate that children accumulate most of their daily steps during light-intensity activity at a mean cadence of ~12 steps per min, whereas moderate-to-vigorous intensity steps were accrued at ~80 per min. Differences in step activity by age and ethnicity were not clear on school days, but on holiday days Polynesian children, older girls, and children from the mid-BMI tertile took less daily steps. There were small to large negative effects on children's step activity due to the onset of evening darkness or colder ambient temperatures. The effects of wet days on step activity were negative but mostly trivial.

Children generally accumulate steps as short bouts of slow-to-fast paced walking and running during play, sports and functional activities of daily life or as sustained periods of moderate-to-brisk walking [196]. Brief bouts of walking do not contribute to the 60 min moderate-vigorous activity guideline [305] whereas continuous walking (≥1 min) at moderate-to-fast pace or running do add to the recommendation [217]. The step-count accelerometer used in our study made it possible to estimate activity intensity, and we determined that children accumulated approximately 75-80% of daily steps during light-intensity activity. The balance of steps were accrued at moderate-vigorous intensity at approximately 80 $steps \cdot min^{-1}$, which would indicate that 4,800 steps would be accumulated during 60 min of moderate-vigorous activity. Our finding is less than a recent review that suggested a guideline of 6000 steps during 60 min of moderate-vigorous activity derived from other studies that did not measure step intensity directly [196]. The step rate at moderate-vigorous intensity accrued during unstructured activity in this study is also less than the 140 steps per min achieved during children's moderate intensity treadmill walking at 66 $m \cdot min^{-1}$ [189].

Step count cut-points are commonly used to determine whether children are participating in sufficient daily physical activity. Only ~10-50% of children from each age tertile in the current study met daily step guidelines [218]. A recent New Zealand study that applied higher accelerometer thresholds [272] derived for children 5-8 y found that no children met the 60-min moderate-vigorous guideline [88]. Studies that simultaneously measured step and accelerometer counts found that preschool children and adolescents participated in 90-100 min of moderate-vigorous activity and accumulated 12,000-13,000 daily steps respectively [89-90]. In these studies, the proportion of children meeting activity guidelines ranged from zero to nearly 100%, which suggests that there are threshold or measurement issues requiring further investigation. Treuth and colleagues noted that defining a universally applicable light-moderate threshold is difficult, as activities such as stair climbing, cycling, and sweeping produced low accelerometer counts per minute for an energy expenditure >3 MET [269]. Reducing the inconsistency between physical activity measurement in future studies may be achieved by improvements in accelerometer calibration [306], field study protocols [307] and standardizing the outputs of different activity monitors [308].

It is widely accepted that physical activity declines rapidly during childhood and adolescence [309]. In the current study, girls followed this trend on holiday days. There were substantial differences in non-school day steps between the girls' age tertiles, whereas on school days there were no clear differences by age. Findings in the present study indicate that age has no clear effect on boy's daily steps. A study of Swedish, Australian and American children also concluded that school-day step activity from age 6-12 y did not follow the typical pattern of activity decreasing with age [218].

Populations with the same ethnicity share similar genetic characteristics, dietary habits, cultural perspectives on body image and physical activity that may account for disproportionate childhood obesity rates between ethnic groupings [310]. New Zealand's Polynesian children have obesity rates 4-5 times that of other ethnicities [302]. Polynesian children in this study were as active as other ethnicities when attending school, whereas during holidays steps per day were less than those of New Zealand European children. Our findings differ from a recent accelerometer study of Polynesian children's physical activity [302] and warrant further investigation to determine if non-school day activity is a contributing factor in higher obesity rates.

BMI-referenced daily step thresholds were developed to relate step activity to healthy body composition [218] based on the precept that healthy-weight children were more active. Contrary to predictions, in the present study girls from the upper-BMI tertile on school days were more active compared with other BMI tertiles. More in keeping with forecasts, the most active boys on holiday days were from the lower-BMI tertile, but interestingly the least active children were from the mid-BMI tertile. On school days, differences in boy's step activity by BMI tertile were unclear. We found similar differences in mean steps per hour for gender, age tertiles and BMI tertiles as those for all children, but the smaller sample size of each tertile could not provide clear effects and warrants further investigation. Studies that tested the precision of BMI-referenced step recommendations found that differentiating healthy body composition by daily step thresholds was not viable [311], nevertheless overweight children were twice as likely not to exceed the daily step guideline [312].

Recent short-duration studies have found that seasonal weather conditions affect children's physical activity [301]. Our study measured weather conditions over 30 months in four geographical locations where climate varied from cool alpine to warm subtropical. Children's step activity decreased substantially on days when the maximum ambient temperature was colder by 10 °C. Children presumably moved indoors after the onset of evening darkness, which decreased all step activity and had substantial moderate to large negative effects on moderate-vigorous intensity steps. Rainfall of more than 1 mm per day had trivial or unclear effects on all step activity except for a substantial negative effect on moderate-vigorous steps on wet school days, when children are less likely to walk to school. Another study that compared independent weather variables reported positive effects associated with warmer temperatures and substantial negative effects of rainfall on children's daily step counts [301]. We included rainfall and temperature in our statistical model so that the synergistic effects of an increase in temperature and lower rainfall, typical of the New Zealand climate, were not confounded, revealing that rainfall had mostly trivial or no clear effects. A potential limitation of this study is that temperature and rainfall were collected at fixed stations and localized rainfall and temperature experienced by participants may have varied. Also the effect of extreme cold or hot ambient temperatures was not measured.

CONCLUSIONS

This study provides data describing children's step activity by intensity associated with weather variables, BMI and demographics. The results indicate that the structure of the school day moderates children's step activity and factors that affect activity are more identifiable when children can self-determine physical activity during holiday days. Active play and walking interventions outdoors that promote step cadences of ~80 min^{-1} during favourable weather are recommended to increase children's daily moderate-vigorous activity. It may be prudent to develop indoor games that encourage higher intensity activity and that are suitable for children to play in confined spaces when environmental conditions compel children to stay indoors.

Acknowledgements

This work was developed through the Understanding Relationships Between Neighbourhoods and Physical Activity (URBAN) study, funded by the Health Research Council (HRC) of New Zealand [grant number: 07/356], and the Neighbourhoods and Health project, supported by the [grant: 08/048]. The funding bodies were not involved in the design, conduct, data collection, management, or publication of the study. The authors also gratefully acknowledge the participants who completed the study, research assistants who collected the data and the territorial authorities for providing the GIS datasets.

CHAPTER 5: POWER OF PLAY: A PRIMARY SCHOOL INTERVENTION TO INCREASE PHYSICAL ACTIVITY IN NZ CHILDREN

This chapter comprises the following paper submitted to 7th Annual International Conference on Kinesiology and Exercise Sciences Conference Proceedings; Athens Greece: McGrath, L. J., Hinckson, E. A., & Hopkins, W. G. (2013). *Manuscript submitted for publication.*

ABSTRACT

Background: Play during recess is an important opportunity for children to accrue moderate and vigorous activity. Actical accelerometers were used to determine the magnitude of additional daily activity accumulated during an extra play period before school. **Methods:** Actical accelerometer data were collected in 79 children (age 9.7 ± 0.4 y, mean ± SD) for 7 to 28 d pre and post a crossover play intervention over 6 months at two schools. The intervention provided children with a supervised play period before school (08:00-09:00) and free access to play equipment for use during playtimes. **Results:** There were reductions in body-mass index of girls in the intervention groups but the effect was trivial (intervention; 17.74 to 17.57 $kg{\cdot}m^{-2}$ vs. control; 17.54 to 17.60 $kg{\cdot}m^{-2}$). Body-mass index of boys receiving the intervention remained constant. Children that provided accelerometer data for each repeated measure had small reductions in moderate to vigorous activity (girls; 49 to 37 min; boys; 59 to 44 min). The percentage of children with valid accelerometer data from measurement week one to four were 79%, 68%, 65% and 47%. Incomplete accelerometer data excluded 50% of children from analysis, which limited accurate determination of the intervention effect. **Conclusions:** An unstructured play intervention implemented in a safe environment before school and during class break should be considered to increase daily physical activity in primary school children.

INTRODUCTION

Improvements in psychological well-being, fitness, bone density and biomarkers of health are achievable if children participate in more play, games, sport, recreation and active transport [8]. Settings that provide opportunities for children to be active include school playgrounds, physical education classes, recreation facilities, school travel and outdoor spaces such as local streets, beaches, parks and sport fields. Children's capacity to be more active is often constrained by lack safe places to play independently [96] especially before and after school. The neighbourhood environment has the potential to affect the long-term health of children by increasing physical activity through play and active commuting [6-7] but modifying the physical environment will take time and it's expensive. Parents require economical, safe, and convenient environments for children to be physically active [313], whereas children need permission to play and access to play areas [96]. Recess has been identified as a setting where children accumulate most of their daily moderate-vigorous activity [160, 205]. The provision of play equipment [135] and enriching the playground environment with soccer goals, basketball hoops and colour-coded play-areas [161] increased children's moderate-vigorous activity.

Children's highly intermittent activity [186] have been tracked using accelerometers because the monitors are a valid and reliable measurement tool [314]. Accelerometers provide detailed information about physical activity patterns as long as children wear the monitors for the allotted periods of time. Researchers investigating children's monitor wear-time found that reminders and incentives contingent on wearing accelerometers were the best strategies to improve compliance [198, 315]. Shorter sampling intervals are recommended for accelerometer studies in children [197]. Also careful selection of the lower boundary of moderate activity is necessary to accurately determine the time spent in moderate-vigorous activity [316]. Accelerometers are imprecise when estimating individual energy expenditure in free-living conditions but are suitable for measuring changes in energy expenditure or daily patterns of physical activity [317]. Past interventions to increase children's activity had small effects on moderate-vigorous activity [135, 161, 318].

The purpose of this study was to implement a crossover design intervention to determine whether providing play and sport equipment for children to engage in self-directed play before school and during class breaks could increase children's daily physical activity.

METHODS

Participants

The Power of Play intervention was implemented in two primary schools in Auckland, New Zealand. Of the 120 children from seven classes, 41 boys and 38 girls (9.7 ± 0.36 y) returned signed informed consent and assent forms. The study was approved by the Institution's ethics committee. The two participating schools were located in North Shore, Auckland. Each school provided 3 x 30 min physical education classes per week, and 30 min morning play and 60 min lunch breaks. The play intervention was implemented during the third school-term July 2007, which is mid-winter in the southern hemisphere, and the second school acted as the control and received the intervention in the spring term before the summer school break, December 2007. Socio-economic status of the schools was estimated using the New Zealand Ministry of Education decile rating system (tenth decile being highest). Both schools were classified as middle socio-economic status (decile 6). The ethnicity of the children were New Zealand European 63.3%, Asian 17.7%, Maori 7.6%, African 5.1%, Pacific Islanders 3.8%, other 2.6%.

Intervention background

Interviews with school principals and teachers identified that an increasing number of children arrived at school approximately 60-90 minutes before classes commenced owing to occupational commitments of parents and caregivers. Teachers preparing for the school day provided children with a space to sit quietly. An alternative to sitting quietly is to provide children arriving early with opportunities to accumulate more daily recommended moderate-vigorous activity [8]. The school playground is perceived by parents as convenient and safe for children's independent play [96]. The earlier school start could potentially fit into the parent's work schedule. The "Power of Play" intervention takes advantage of circumstances prevailing in many families, past intervention success, and the convenient school environment to create an additional opportunity for children to participate in self-directed play.

School sport and play environment

The "Health and physical education in New Zealand curriculum" [319] provides physical activity, sport studies and outdoor education guidelines to develop children's essential physical skills for use in play, games, formal exercise, dance, sport and daily life. To facilitate skill development schools erect basketball and netball hoops, tennis, volleyball and badminton nets on asphalt play courts in conjunction with physical education modules. Athletic running tracks, long jump pits, rugby, soccer and hockey goal posts are set up on grass playgrounds to coincide with seasonal sport programs. Permanent playground equipment of slides and climbing apparatus and covered outdoor play areas are also normally provided at New Zealand schools. New Zealand schools have indoor gymnasiums, asphalt courts and extensive grass playgrounds that provide the infrastructure for play, games and sport participation during play breaks. The element not always available during play breaks is sport and play gear that children can use for self-exploration and development of the physical skills necessary for participating in games, sport or play.

Intervention equipment

Sport equipment included cricket and baseball sets, rugby, soccer, netball and volley balls, badminton and tennis rackets, hockey sticks, sprint ladders, plyometric hurdles and soccer target hoops. Play equipment included, coloured cones, hopscotch mats, skipping ropes, elastic jumping bands, frisbees, and a variety of balls including irregular shaped, large bouncing, soft tag, tennis and swiss balls. The budget for the play equipment was NZ$3 per child and a total of NZ$2,000 was spent on equipment purchased at retail and variety stores.

Supervision

Play equipment and supervision of the before school play period were provided. The play area was enriched with sprint ladders, plyometric hurdles, coloured cones and hopscotch mats. Sport and game gear was placed in bags in the playground for free access by children during breaks. Children's play was self-directed and supervision was limited to monitoring appropriate play behaviour and returning discarded play items back to the gear bags.

Experimental design

The "Power of Play" crossover design intervention was implemented for seven weeks in a single school-term providing children with free access to play and sport equipment during an optional supervised play period before school 08:00-09:00 and during class breaks (Figure 5.1). Two weekend and five school days of Actical 15-s accelerometer data were collected pre and post implementation of the play intervention at each school.

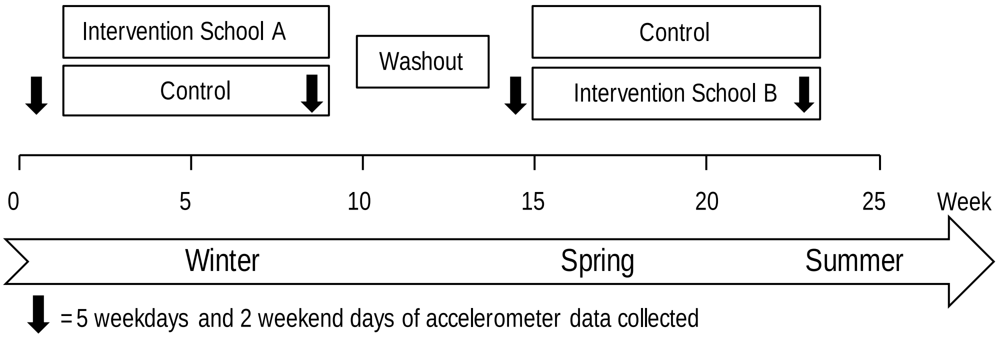


Figure 5.1. “Power of Play” intervention design.

Instruments

Accelerometer

The Actical accelerometers (Mini-Mitter Co., Inc., Bend, OR) which are omni-directional and water-resistant were used. Actical accelerometers had the best intra- and inter-instrument reliability compared to Actigraph (7164) and AMP-331 monitors when tested using a mechanical laboratory setup [320]. ISAK protocols were followed when measuring children’s height and weight using a portable stadiometer (Design No. 1013522, Surgical and Medical Products, Seven Hills, Australia) and digital scales (Model Seca 770, Seca, Hamburg, Germany). Children were required to demonstrate competency in fitting elastic belts, with accelerometers attached, so that the monitors were located above the right hip bone. The children were instructed to wear the monitors at all times other than sleep, bathing or swimming. In a recent study, children’s self report logs were found to be unreliable and there were little differences between non-wearing times estimated from logs and accelerometers [321] so logs of non-wearing times were not kept. To encourage compliance children placed stickers on a classroom chart indicating when accelerometers were worn. After each measurement week children received incentive-based rewards of novelty toys, sweets and health-food bars to the value of NZ$2 along with a personal pedometer (NZ$2) on completion of the study.

Data reduction

Accelerometer data were exported from Actical “1R” (single regression) files. The standard school day was defined by winter daylight hours 07:00-18:00 then divided into time spent in different settings, at home 07:00-07:59, before school play & commuting 08:00-08:59, class, school play breaks, commuting home 15:00-15:29, and at home after school 15:30-18:00. Accelerometer counts accrued during children’s normal sleep times (23:00-06:00) were excluded from analysis. The start of accelerometer worn time was defined as the time of the first non-zero count after 06:00 and the end time was designated as the last non-zero count before 23:00. Researchers have determined accelerometer non-wearing times as periods of continuous zeros ranging from 10-180 min [322]. From our previous work we have found that periods of continuous zeros could exceed 60 min during class time, so we opted for a period of >120 min to represent non-wear time.

Each day ~20% of children’s activity data were removed from analysis if the measurement period was <9 h between 07:00-18:00 or the total accelerometer count for the day was implausibly high (>700,000) or low (<70,000) indicating a faulty accelerometer. When participant data were not available the cause was ascertained. Causes for monitor failure were determined when the accelerometer was returned and qualitative data were collected to identify reasons for non-compliance.

Statistical analysis

Analyses were performed in the Statistical Analysis System (Version 9.1, SAS Institute, Cary, NC) using Proc Mixed. The dependent variable was the proportion of time spent at a given intensity in each daily setting. The arcsine-root transformation produced uniform errors across all intervals. Estimates were back transformed and expressed as time spent at different intensities in each setting. Puyau et al. [217] thresholds and sampling intervals of 15 s were applied to children's accelerometer data. Any slight mismatch between the back transformed effects and the differences in the means arising from the use of the non-linear arcsine root transformation were adjusted so that time spent in different intensities and settings totaled 100%. Inferences were based on standardised magnitude thresholds [220] using 1000 bootstrap samples; uncertainty in effects was expressed as 90% confidence intervals. If the 90% confidence interval overlapped zero and it was uncertain whether the effect could be substantially positive or negative, the effect was deemed unclear; other effects were clear.

RESULTS

Participant characteristics

Descriptive characteristics of participants at the first and last measurement week are shown in Table 5.1.

Table 5.1. Pre and post intervention descriptive statistics (Mean ± SD)

	Pre intervention		Post intervention	
Gender	Female (n=38)	Male (n=41)	Female (n=32)	Male (n=37)
Age (y)	9.4 ± 0.4	9.8 ± 0.4	9.9 ± 0.4	10.3 ± 0.4
Weight (kg)	34.2 ± 6.1	36.3 ± 7.1	34.4 ± 6.2	37.8 ± 7.0
Height (cm)	137.7 ± 6.3	137.4 ± 6.7	139.6 ± 6.5	140.1 ± 7.0
BMI ($kg \cdot m^{-2}$)	17.9 ± 2.8	19.1 ± 2.8	17.6 ± 2.5	19.2 ± 2.7

Children's height increased by an average of 2.0 cm for those that remained in the study long term. The change in body-mass index of girls and boys during the intervention are shown in Figure 5.2. The differences in body-mass index were trivial.

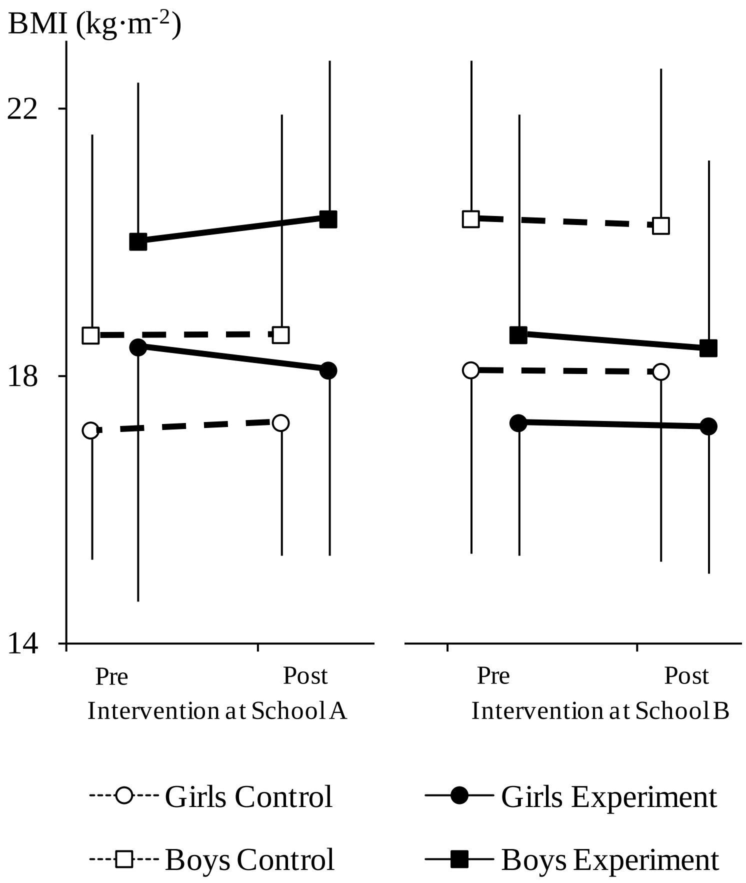


Figure 5.2. “Power of Play” Intervention effect on body-mass index.
Data are means; error bars are standard deviations.

Changes in physical activity at different intensities, time periods and settings pre and post intervention are shown in Table 5.2. There was a small decrease in time children spent in moderate-vigorous activity post intervention.

Table 5.2. "Power of Play" intervention effect on time spent at different intensities for boys and girls from both schools.

Time spent at intensity	Before school	Class			School play		After school
	07:00-08:59	09:00-10:29	11:10-12:29	13:30-14:59	10:30-10:59	12:30-13:29	15:00-17:59
Vigorous activity (s)							
Boys pre intervention	23	13	10	13	33	88	24
Boys post difference	-7	-11	-5	-13	-14	-14	14
Girls pre intervention	15	7	12	13	13	52	29
Girls post difference	-4	-4	-4	-4	0	0	-14
Moderate activity (min)							
Boys pre intervention	12	2.7	3	4.3	6	15	15
Boys post difference	-1.8	-1.7	-2	-2.2	0.7	0.5	-4.8
Girls pre intervention	8.5	2.1	3	3.7	4.9	13	13
Girls post difference	-1.7	-1.2	-1.3	-0.9	0	-3.8	-2.6
Light activity (min)							
Boys pre intervention	31	15	15	22	10	20	44
Boys post difference	-3.3	-3.4	-3.2	-3.6	-0.2	-1.4	-6.1
Girls pre intervention	26	12	14	18	10	22	43
Girls post difference	1.2	-1.5	-2.2	-2.4	0.7	-1.4	-4.7
Sedentary time (min)							
Boys pre intervention	77	72	72	64	13	24	120
Boys post difference	5.2	5.3	5.3	6	-0.2	1.2	10.7
Girls pre intervention	85	76	73	68	15	24	120
Girls post difference	0.6	2.7	3.6	3.3	-0.7	5.2	7.5

The percentage of children that provided valid data for analysis and the reason children had insufficient days of data are shown in Table 5.3. Actical monitors were worn by participants for a total of 295 weeks and 21 accelerometers (7%) failed to record that weeks activity data. Children excluded from the analysis for non-compliance with the study protocol mostly did not wear the monitor owing to forgetfulness. The difference between physical activity levels of children that were included in the final data set (counts·min^{-1} boys; 650 ± 190; girls; 600 ± 170, mean ± SD) were trivial compared with those excluded (boys; 610 ± 220; girls; 500 ± 160).

Table 5.3. Percent children providing accelerometer data at each repeated measure during “Power of Play” crossover intervention.

			Reason Data Not Provided					
		Valid Data Collected	Non-Compliance	Faulty Monitor	Withdrawn	Monitor Lost	Absent	Left School
Pre Intervention School A	Girls	79	16	5				
	Boys	78	15	7				
Post Intervention School A	Girls	69	26	3			2	
	Boys	67	23	10				
Pre Intervention School B	Girls	70	24	2	2		2	
	Boys	61	20	7		7	5	
Post Intervention School B	Girls	52	22	7	10		2	5
	Boys	42	29	15	8	2	2	2

DISCUSSION

The aim of this study was to implement a crossover play intervention in two New Zealand primary schools to determine whether an additional play period before school and free access to play equipment during class breaks could increase children’s moderate-vigorous activity. In the current study, with the exception of boys from the school receiving the intervention during winter, there were trivial reductions in children’s body-mass index. There was also a small decrease in moderate-vigorous activity post intervention in children that provided valid data for each repeated measure.

In the present study, girls reduced and boys maintained their body-mass index pre and post the experiment period. A meta-analysis of school-based physical activity interventions found similar small effects on weighted mean difference in body-mass index [323]. Body-mass index increases with children’s age and development so maintaining or achieving small reductions in body-mass index for paediatric populations may be considered a successful outcome [324]. An interesting finding of the current study was that body-mass index was maintained while moderate-vigorous activity decreased. There were similar reductions in body-mass index [325] even though there were no differences in accelerometer measured physical activity in an intervention that promoted good nutrition and provided additional physical education classes [172]. In a two year intervention to increase American girl's physical activity, there were also no significant differences in accelerometer measured moderate-vigorous activity and body-mass index [318].

Reasons accelerometer data were not available were examined to evaluate potential explanations for decreased moderate-vigorous activity post intervention. The percent of children not adhering to the study protocol was similar to that reported in previous studies [198, 315] and was not considered to have influenced results. Similarly, Actical monitor failure rate in this study was comparable with the 9% of Actigraph motion sensors that failed in another study [198] and also not deemed to have biased results. The inability to retain children in the study long-term may be considered out of the control of researchers and may require increased sample size to account for data lost in this manner.

There were no differences in physical activity levels between children excluded or included in the final data set. Other factors may be confounding the results. The primary schools in this study adhere to the "Health and physical education in New Zealand curriculum" [319] that uses sport, game, formal exercise and dance delivered in three week modules to develop children's essential physical skills. The varying intensity and level of participation between modules for example winter cross country running and summer cricket may have been a confounding factor in this study. Moderate rainfall and reductions in daytime temperature are associated with small to moderate negative effects on New Zealand children's activity [301]. The post intervention measurement at the winter intervention occurred in spring, which is a period of high rainfall in New Zealand that may have kept children indoors reducing daily physical activity levels.

There were limitations to the study. While the sample size was appropriate for a crossover design, loss of accelerometer data reduced the number of participants providing activity data, which lead to uncertainty in the effect of the additional play period on children's physical activity. Also seasonal differences in physical activity and effects of weather on activity were not determined, which may have confounded results.

CONCLUSIONS

An unstructured play intervention implemented in a safe environment before school and during class break may be an additional strategy to increasing daily physical activity in primary school children. To increase certainty in detecting small intervention effects in accelerometer studies sample sizes may need to be increased to account for activity data loss. The positive effects of the play intervention on limiting children's increased body-mass index warrant further investigation.

Acknowledgements

The authors thank the children, parents and schools that participated in this study, Purvi Chhichhia who was essential for collecting the data, and Sport and Recreation New Zealand and SPSS New Zealand Ltd who assisted with the provision of children's play equipment.

CHAPTER 6: EXAMINING LOSS OF ACTIVITY DATA IN ACCELEROMETER STUDIES WITH CHILDREN

This chapter comprises the following paper submitted to Pediatrics International: McGrath, L. J., Hinckson, E. A., & Hopkins, W. G. (2013). *Manuscript submitted for publication.*

ABSTRACT

Background: Improving data collection practices in accelerometer-based studies could minimize data exclusion that may bias physical activity estimates. Reasons for non-compliance and other factors that affect data inclusion were examined. **Method:** Actical accelerometer data of 79 children (age 9.7 ± 0.4 y, mean ± SD) were collected for seven days in four repeated measurements during implementation of a play intervention. Factors that reduced days of valid activity data were examined. **Results:** From a maximum of 28 days girls and boys provided 19 ± 6 and 17 ± 7 valid days of accelerometer data respectively. Data from 50% of children were excluded from analyses. Twenty–two percent of the children did not wear the monitors for sufficient $h \cdot d^{-1}$ or $d \cdot wk^{-1}$ and 13% did not remain in the study long term. Faulty and lost monitors accounted for 14% of data loss. Only 18% of the children had seven days of valid data at each repeated measurement. The common reason offered by children that withdrew from the study was discomfort of wearing the monitor. **Conclusion:** To increase compliance, researchers should invest in motion sensors that are comfortable to wear continuously, that detect wear time and are less prone to failure.

INTRODUCTION

Accurate and objective measurement of children's physical activity is necessary to determine the effect of interventions aimed at increasing daily activity. Determining children's physical activity is difficult owing to the complexity of their movement patterns. Free-living children engage in brief (3-36 s) periods of vigorous activity interspersed with bouts of light and moderate activity of varying duration (3-1200 s) [186]. Accelerometers are a valid and reliable means of tracking [314] or measuring children's activity patterns as they provide detailed information about physical activity and are used internationally to evaluate activity levels.

Practical factors should guide accelerometer selection such as cost, size, weight, memory capacity, battery life, water-resistant capability, minimum epoch and the maximum number of days monitoring. Accelerometers may be worn on the wrist, ankle, or at the recommended waistline locations of the hip or middle of the back for which participants are responsible to position the monitor correctly [199]. Selecting an accelerometer with high intra- and inter-monitor reliability is important as reliability is used to determine sample size and the minimum number of valid days [326]. Better monitor reliability offer more precision in single measurements and provides more accurate tracking of changes in activity levels [327]. Shorter epochs are recommended for accelerometer studies in children [197]. Researchers' are required to source software programs that are capable of managing the large volumes of collected data, perform the appropriate statistical analysis and summarise accelerometer counts into meaningful outcome measures. Decisions on data inclusion criteria are required such as identifying non-wear time [322], setting the minimum hours worn for a valid day and the least number of valid weekdays and weekend days [199, 287].

Even with accurate monitors and the best study design, comprehensive information about activity patterns is only obtainable if children wear the monitors for the allotted periods of time. Trost et al. [199] developed a set of strategies to encourage compliance. In studies that implemented strategies to improve compliance it was found that other factors contributed to loss of activity data including children transferring school or withdrawing, lost accelerometers and mechanical malfunctions [198, 315]. To limit the effect of malfunctioning monitors on the activity data collected it was recommended that researchers invest in a mechanical shaker to calibrate accelerometers [271, 320].

The purpose of this study was to investigate contributing factors, in conjunction with compliance that result in reduced activity data in a repeated-measurement study. A set of operational tests to identify faulty motion sensors before field placement were also implemented. Based on outcomes that occurred during implementation of the crossover intervention, additional strategies were developed that could potentially increase the proportion of valid activity data collected in future studies.

METHODS

Participants

Two primary schools in Auckland, New Zealand, consented to participate in the study. There were 120 eligible children from seven classes of which, 79 children (41 boys and 38 girls; age 9.7 ± 0.36) volunteered and returned signed informed consent and assent forms. The participating schools were located in the same geographical area (North Shore, Auckland) with daily morning and lunch playtimes of 30 and 60 min, plus three 30 min physical education classes per week. The study began in July 2007 and finished in December 2007. The participating schools were representative of those from middle socio economic background. The ethnic background of the participants were; New

Zealand European 63.3%, Asian 17.7%, New Zealand Maori 7.6%, African 5.1%, Pacific Islands 3.8%, other 2.6%. The study was approved by the institutional ethics committee. Descriptive characteristics are shown in Table 6.1.

Table 6.1. Descriptive statistics (Mean ± SD) by gender

Gender	Female (n=38)	Male (n=41)
Age (y)	9.4 ± 0.4	9.8 ± 0.4
Weight (kg)	34.2 ± 6.1	36.3 ± 7.1
Height (cm)	137.7 ± 6.3	137.4 ± 6.7
BMI ($kg \cdot m^{-2}$)	17.9 ± 2.8	19.1 ± 2.8
Weekday Actical $count \cdot min^{-1}$	548 ± 169	630 ± 205
Weekend day Actical $count \cdot min^{-1}$	382 ± 154	301 ± 129
Weekday ‘start-time’ (h:mm)	7:36 ± 1:08	7:33 ± 1:01
Weekend day ‘start-time’ (h:mm)	8:56 ± 1:57	8:24 ± 1:26
Weekday ‘end-time’ (h:mm)	20:10 ± 1:58	20:23 ± 2:05
Weekend day ‘end-time’ (h:mm)	20:44 ± 1:58	21:08 ± 1:23
Weekday time monitor worn (h:mm)	12:35 ± 2:05	12:51 ± 2:03
Weekend day time monitor worn (h:mm)	11:47 ± 2:46	12:42 ± 1:58

Intervention design

Two weekend and five school days of accelerometer data were collected pre and post the “Power of Play” crossover intervention (four measurement periods) in two schools (Figure 6.1). While the focus of this paper is not the effect of the intervention but the compliance during the four measurement periods, briefly, the intervention provided children with a supervised play period before school 08:00-09:00 and free access to play equipment during playtimes for seven weeks during a school-term. The first school received the intervention in the mid-winter term, and the second school received the intervention in the spring term before the summer school break. There were five weeks of “washout” prior to the second school receiving the intervention.

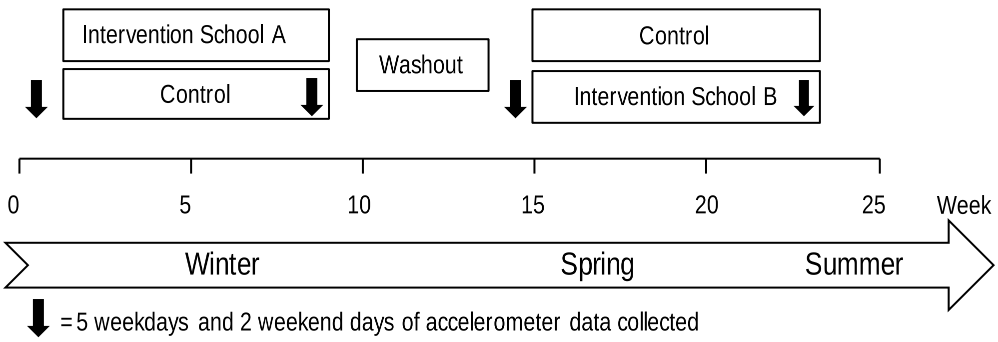


Figure 6.1. Intervention study design.

Instruments

Accelerometer

The waterproof omni-directional Actical (Mini-Mitter Co., Inc., Bend, OR) accelerometer was used to measure children's physical activity. During mechanical laboratory testing, the Actical accelerometers demonstrated the best intra- and inter-instrument reliability when compared to Actigraph (7164) and AMP-331 monitors [320]. Using indirect calorimetry as the criterion measure the Actical monitors reliably classified children's activities by intensity at the respective agreement levels; sedentary (0.98), moderate (0.86) or vigorous (0.86) [272]. The Actical was set to the manufacturer's minimum epoch of 15 s, which is consistent with the duration of children's physical activity bouts which typically last ~20 s across all intensities [328-329].

Before receiving the accelerometers, children's height and weight were measured using a portable stadiometer (Design No. 1013522, Surgical and Medical Products, Seven Hills, Australia) and digital scales (Model Seca 770, Seca, Hamburg, Germany). BMI was calculated as weight (kg) divided by height squared (m^2). Following training children were required to demonstrate competence in removing and fitting the accelerometer waist belts. The waist belt was fitted so that the accelerometer was positioned immediately above the right hip bone. Children were instructed to remove the accelerometer when bathing, swimming or sleeping. Non-wear time logs were not kept as children's self-reported information is unreliable and the degree of underestimation of overall activity is trivial [330].

Accelerometer preparation

Before the study commenced accelerometer batteries and 'O' rings were replaced and monitors were field tested for functionality. Multiple accelerometers were worn on a single waist belt during self-paced running (200 m), walking (5 min) and one hour of sitting interrupted by standing or short duration (5-15 s) walks. Accelerometer data were downloaded to identify faulty monitors and comparisons were made to determine whether each monitor's total count was within ±10% of the mean total count for all accelerometers. During the study additional functional checks were conducted; i) activated accelerometers were placed on a shelf overnight and were checked the next day for accumulation of false counts above zero and ii) activated accelerometers were vigorously hand shaken. The additional checks caused monitors with misaligned 'O' rings, faulty sensor mounts or loose battery terminals to fail the functionality tests. The functional tests identified 22 of the 105 accelerometers as malfunctioning.

Compliance procedures

To encourage compliance children were provided stickers to place on a classroom wall chart indicating when accelerometers were worn. When accelerometers were returned children were asked to identify reasons for non-compliance. After each measurement week children received incentive-based rewards such as novelty toys, sweets and health-food bars to the value of NZ$2 and a personal pedometer (NZ$2) on completion of the study.

Children's compliance was analysed by examining periods of continuous zero accelerometer counts. Zero counts arise when the accelerometer is not worn or when movements during a sampling interval do not exceed the preset threshold of 0.05g. Monitor non-wearing times have been defined by others as periods of continuous zeros ranging from 10-180 min [322]. We opted for a 60-minute allowable interruption period and 10-hours-per-day wear time criteria which typically results in ~85% of children with at least four days of valid activity data from seven days of data collection [287].

Data reduction

Accelerometer counts accumulated between 23:00 and 06:00 were excluded from analyses to negate the effect of children wearing the monitor during sleep. The first non-zero accelerometer count after 06:00 and the last non-zero count before 23:00 were used to designate the beginning and end time for accelerometer recording. Weekday accelerometer $count \cdot min^{-1}$ data were ranked highest to lowest and children's activity data were allocated into tertiles; low active, moderate, and high active. We examined all accelerometer records to determine if data were accrued on faulty or well functioning monitors. Accelerometer files were considered to be trustworthy if $count \cdot min^{-1}$ data were in the biologically plausible range (0-15,000) [287], children accumulated reasonable $counts \cdot min^{-1}$ intermittently throughout the day as well as during active periods such as recess. An accelerometer was considered faulty when excessive accelerometer counts were accumulated during normal sleep hours (00:00-04:59). Motion sensors with improbable $count \cdot min^{-1}$ data were assessed to establish the cause of monitor failure and the activity data was removed from analyses.

Statistical analysis

Descriptive statistics are presented as means and standard deviations. Main accelerometer data analyses were performed in the Statistical Analysis System (Version 9.1, SAS Institute, Cary, NC) using Proc Mixed. Results are presented as group mean differences with 90% confidence limits (CL) [331,219]. Children's activity data were allocated into tertiles (low, moderate and high physical activity) based on mean daily count·min^{-1} data. Group mean differences in valid days provided between the tertiles were compared using paired t-tests [220]. Reasons for non-compliance were also documented. Clear effects for differences in group means are shown as the observed magnitude, with a qualitative descriptor of that magnitude. The descriptors used were: 0.0 - trivial; 0.2 – small; 0.6 – moderate; 1.2 – large; 2.0 [220]. If the 90% confidence limit overlapped zero, the effect was deemed unclear.

RESULTS

Participant characteristics

Six children withdrew from the study. The primary reason for withdrawal was the discomfort of wearing the monitor daily. One boy lost his accelerometer and withdrew at his parent's request. The percent of children included or excluded from final analyses are presented in Figure 6.2.

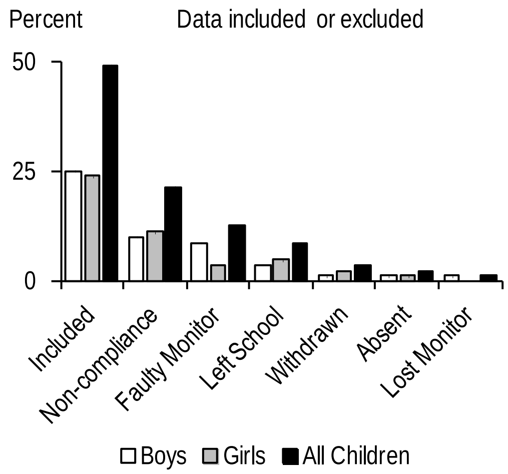


Figure 6.2. Proportion of valid days (monitor worn ≥10 h·d^{-1}) and reason for loss of activity data.

Overall, 20 boys and 19 girls had sufficient valid days of accelerometer data at the four repeated measurements to meet inclusion criteria. Children absent for an entire measurement week were excluded from analyses. The percent of children with four or more valid days of data at each measurement week is presented in Figure 6.3 and the reasons for data loss or exclusion for boys and girls are presented in Figure 6.4. The percent of children with valid activity data assigned to either control or experimental schools at each measurement week is shown in Figure 6.5. The difference in mean valid days by order of assignment to experimental or control school respectively for girls (-0.18 ± 0.54) (difference in standardized means ± 90% CL) and boys (-0.02; ± 0.52) were unclear.

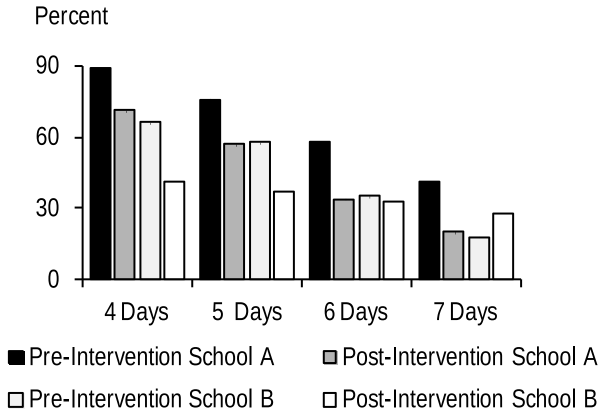


Figure 6.3. Proportion of children with 4-7 days of valid activity data for the four repeated measurements.

After applying the criteria for accelerometer not worn (60-min of continuous zero accelerometer counts) and 10-hours-per-day wear time; girls had 19 ± 6 (mean ± SD) and boys had 17 ± 7 valid days of accelerometer data and non-compliant days were 6 ± 5 for girls and 7 ± 6 for boys. Differences in compliance between activity tertiles are presented in Table 6.2.

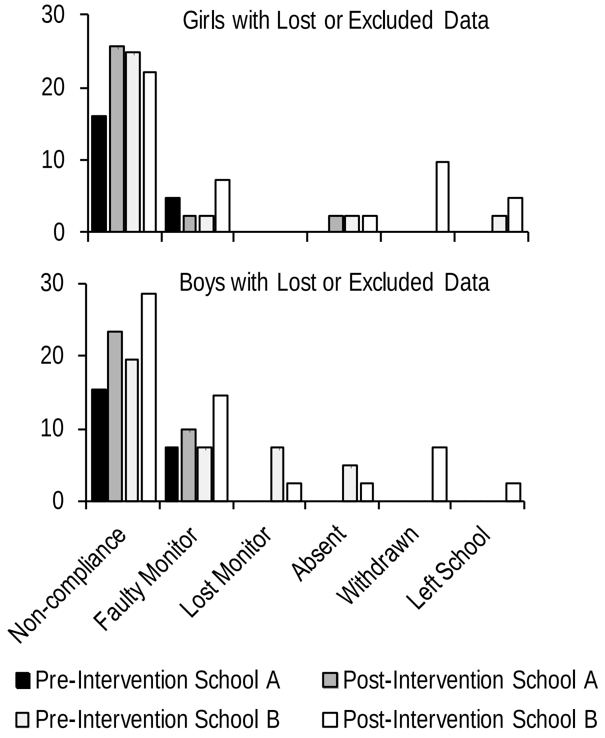


Figure 6.4. Proportion of data loss or excluded data for boys and girls by reasons and intervention school order.

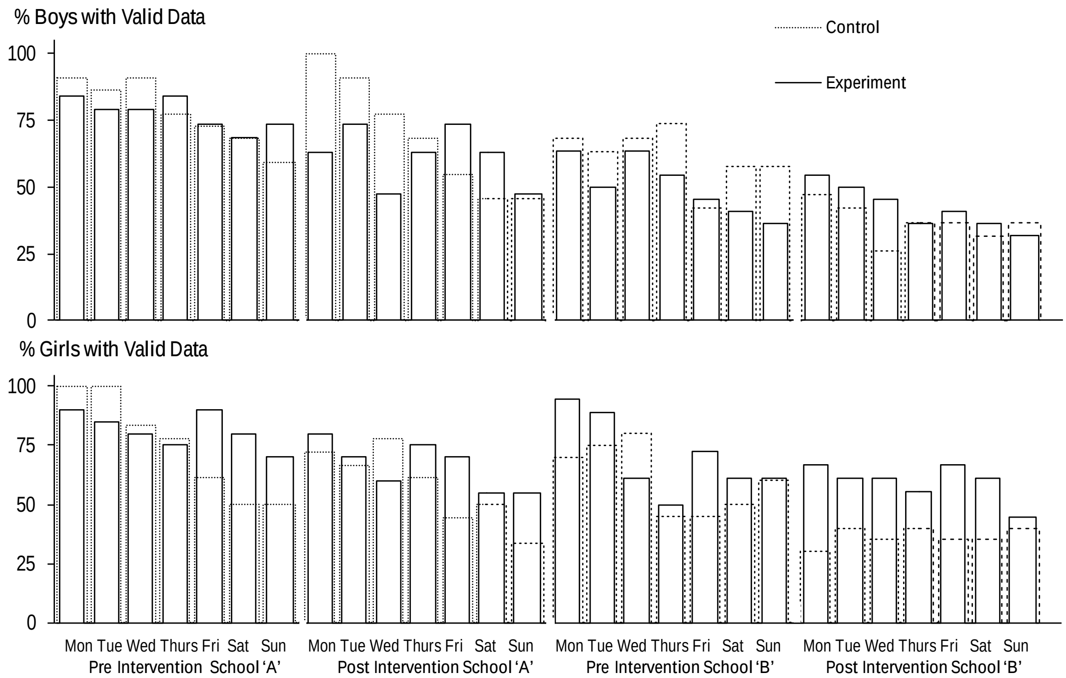


Figure 6.5. Daily proportion of valid activity data (monitor worn ≥10 h·d^{-1}) by gender and group assignment.

Table 6.2. Differences in the number of valid days of activity data collected for low, moderate and highly active children.

Activity Tertiles	Count·min^{-1}·d^{-1} (Mean ± SD)			
	Female	Male		
Low	380 ± 70	420 ± 80		
Moderate	520 ± 40	610 ± 60		
High	740 ± 120	860 ± 120		
	Valid days activity data (Mean ± SD)		Standardized mean ± 90% CL; magnitude	
	Female	Male	Female	Male
Low	18 ± 5	17 ± 8	-0.68 ± 0.67; unclear	0.18 ± 0.67; unclear
Moderate	20 ± 6	16 ± 8	0.26 ± 0.65; unclear	-0.26 ± 0.64; unclear
High	15 ± 7	17 ± 5	-0.51 ± 0.67; small	-0.01 ± 0.64; unclear

Week day mean accelerometer count·min^{-1}·d^{-1} was used to allocate children into low, moderate and high active tertiles. Comparisons are low vs moderate, moderate vs high and high vs low tertiles. Inferences for the differences in standardized means are shown as standardized magnitude thresholds (0.0 - trivial; 0.2 – small; 0.6 – moderate; 1.2 – large; 2.0) [220]. Effects were deemed unclear if the ± 90% CL (confidence limit) over lapped zero and it was uncertain whether the effect could be substantially positive or negative.

Children provided similar reasons for not wearing the monitors. During each measurement week, 82% of children forgot to wear the monitors on one or more days. On at least one occasion, two-thirds of children did not replace their accelerometer after bathing or organised sport and half of children removed monitors in the late afternoon because of discomfort. One monitor was lost when the elastic strap slipped loose during outdoor play and another after removal for swimming.

When monitors were returned 21 were found to be defective. Five accelerometers malfunctioned in the first measurement week. Two accelerometers that passed retesting failed a second time and three replacement accelerometers were also faulty. An examination of the accelerometer records of faulty motion sensors revealed that monitors accrued spurious counts during children’s normal sleep times 23:00-05:59 or recorded abnormally high counts 06:00-22:59. Two accelerometers malfunctioned in the third measurement week recording high activity counts at unusual hours (00:00-05:00) suggesting that the internal clock had reset for unknown reasons. Six-monthly battery changes before the fourth measurement week, resulted in nine accelerometers recording sporadic periods of data or no data. Nil accelerometer failures were attributable to user error.

DISCUSSION

In the current study factors that reduced the days of valid accelerometer data collected in four measurement points during a crossover intervention in two New Zealand primary schools were identified. Results from this study will hopefully inform strategies to increase the proportion of valid accelerometer data in future studies. In the present study, accelerometer data were excluded from analyses because children did not wear the accelerometers for sufficient $h \cdot d^{-1}$ or $d \cdot wk^{-1}$. Monitor failure and children not staying in the study long-term resulted in greater loss of accelerometer data than non-compliance.

Motion sensor accuracy is irrelevant when children fail to wear accelerometers for the allotted periods of time. Non-compliance in the current study was lowest at baseline and almost doubled in the second measurement for girls and was greatest for boys in the final measurement week. In our study, the proportion of children with 4 and 5 days of valid activity data after the first measurement week was slightly higher than adolescent studies [198, 315] that employed strategies to increase compliance. However, when provided with monetary incentives, more adolescents wore the accelerometers for 6 and 7 days [198, 315]. In the current study, girls from the high-active tertile provided fewer valid days of data than those from the low-active tertile, whereas in boys there was no clear difference in valid days between activity tertiles. A similar result was observed in other studies with adolescent boys [315]. Oversampling has been suggested as a strategy to offset low compliance [198]. One in five children in the present study had valid activity data for six or more days at each repeated measurement, which suggests that sample sizes may need to be increased two to five times dependent on the inclusion criteria applied by researchers. Such large increases in sample size may not be a cost effective or practical solution for offsetting low compliance in repeated measurement studies.

In most studies that used motion sensors to measure physical activity, participants were instructed to remove monitors before bathing, swimming or sleep. Children in the present study were given the same instruction. Removal of the monitor however, resulted in some children forgetting to refit the monitor after the relevant activity. A study in adolescents also reported that forgetfulness to refit the monitor was one of the main reasons for data loss [315]. One third of children in the current study neglected to wear the monitor to school but upon returning home almost all children refitted the device. Some children reported that they had worn the monitors during sleep. Accelerometers are commonly used to monitor sleep so it would be possible to instruct participants in future studies to wear monitors 24 $h \cdot d^{-1}$ to improve compliance (preferably on the wrist and provided the monitors were waterproof, see discussion below).

Many portable electronic devices were designed to be robust enough to achieve a five-year failure-free lifespan that includes accidental drops and mishandling during normal customer usage [332]. In the current study, accelerometer failure was high (7%) and the second most likely cause of activity data loss. Actical and Actigraph (9%) failure rates [198] are similar so it had been suggested that unit specific calibration of accelerometers is required [271, 320]. A systematic evaluation of Actigraph accelerometers calibrated prior to field placement recommended that quality checks of instruments is more important than calibrating monitors in a mechanical setup [333]. Initialisation malfunctions and monitor failures resulting from dropping or rough handling were found to be the cause for Actigraph failures [198]. In our study, Actical accelerometers were three times as likely to fail for boys than girls, which suggests that the energetic movements of boys were sufficient to cause monitors with defective ‘O’ rings, sensor mounts or battery terminals to malfunction. During our study, we developed functional tests to identify faulty Actical accelerometers and used the protocol in a 2,500 participant study [206] that reduced monitor failure to below 0.5%.

Children failing to stay in the study long-term accounted for the remainder of data loss. Reasons children offered for withdrawing from our study was the burden and / or discomfort of wearing the monitor. A study in adolescents found that fashion or social conformity [315] were reasons for not wearing the monitors. Wrist placement of Actical monitors accurately predicted activity energy expenditure [334] and may be comfortable for participants to wear continuously. A recent study of commercial motion sensors designed to be fashionable to wear, like the Polar RS800sd shoe accelerometer, were also accurate at measuring running stride rates and could potentially measure free-living physical activity [335]. To increase compliance in future research activity monitors should be designed to be fashionable and comfortable to wear.

Key lessons learned from our findings include: i) implementation of a set of field checks prior to each measurement period to minimize monitor failure, ii) continuous wearing is a potential solution to children forgetting to refit the monitor after sleep or bathing, iii) participants with discomfort issues need to be identified and resolved throughout the study.

The study had the following limitations/delimitations. The days of valid activity data collected were applicable to children of primary school age in New Zealand. The effect of providing incentives and the influence of seasonal clothing choices on the percentage of children wearing accelerometers is unclear as the effect of different compliance strategies and seasonal change were not systematically investigated. Only faults associated with Actical monitors were evaluated and the functional checks suggested are mostly applicable to this model accelerometer.

CONCLUSIONS

In summary, half of children's results were omitted from analysis as a consequence of insufficient activity data. It is recommended that researchers investigate strategies that allow participants to wear monitors continuously. Researchers should evaluate motion sensors that detect wear time, are robust, waterproof, failure-free, comfortable and fashionable for participants to wear. In the interim, mandatory quality control checks of monitor functionality before placement on participants may increase the days of valid data collected. Increases in sample size should be considered to account for children that do not remain in repeated measurement studies long-term. The challenge of future physical activity research is to decrease the requirement to make assumptions about missing activity data.

Acknowledgements

The authors thank the children, parents and schools that participated in this study, Purvi Chhichhia who was essential for collecting the data, and Sport and Recreation New Zealand and SPSS New Zealand Ltd who assisted with the provision of children's play equipment.

CHAPTER 7: ACCELEROMETER SAMPLING INTERVAL AND INTENSITY THRESHOLDS EFFECT ON MEASURES OF CHILDREN'S PHYSICAL ACTIVITY

This chapter comprises the following paper submitted to Journal of Physical Activity & Health: McGrath, L. J., Hinckson, E. A., & Hopkins, W. G. (2013). *Manuscript submitted for publication.*

ABSTRACT

Background: Choice of intensity thresholds and sampling interval measured with accelerometers may influence conclusions made about children's habitual physical activity. The aim of this study was to quantify children's daily physical activity using Actical accelerometers by comparing estimated activity when using manufacturer thresholds and sampling at 60-s intervals, with thresholds of Puyau and colleagues sampling at 60-s and 15-s intervals. **Method:** Accelerometer data were collected from 79 children (age 9.7 ± 0.4 y, mean ± SD) for 7 d periods in winter and spring 2007. Proportions of time spent at different activity intensities were compared via standardisation and bootstrapping. **Results:** Intensity threshold and sampling interval had clear small to large effects on time spent in sedentary, light, and vigorous activity in various home and school settings. Moderate activity showed little effect of interval but very large effects of threshold. There were major effects of threshold and interval on the proportion of children meeting physical activity recommendations (65-100%). School free-play and commuting-related activity accounted for most of the moderate-vigorous activity (34, 38, 83 min and 49, 51, 139 min respectively, depending on the threshold and interval used). Differences between boys and girls were generally trivial. **Conclusions:** Choosing intensity thresholds and sampling interval to estimate children's physical activity need to be considered when using accelerometers. As a secondary

conclusion, we observed that the school environment is a major contribution to daily moderate-vigorous activity in children.

INTRODUCTION

Physical activity guidelines recommend that children engage in 60 min of moderate-to-vigorous physical activity daily to accrue benefits to health in general [8], bone health [336] and glucose metabolism [337]. The school setting, especially recess, is a valuable opportunity for children to contribute to their recommended activity levels [205, 338]. Determining the relationship between children's physical activity and health is only feasible when measurement instruments accurately capture habitual physical activity. Children's physical activity is highly intermittent [329], which makes accurate measurement of activity difficult. Accelerometers are a popular measurement tool, because they objectively and reliably quantify the volume of children's physical activity across the sedentary to vigorous intensity range [314]. The small size and large memory capacity of the latest accelerometers make them suitable for children to wear unobtrusively for extended periods of time [339]. There are several potential problems with the use of accelerometers: thresholds for activity intensities vary substantially between calibration studies [339], and the practice of using sampling intervals of 60 s fails to accurately capture children's high-intensity activity [340]. However, we know from previous literature that shorter sampling intervals decrease apparent time spent in light-moderate intensity activity, increase total duration in vigorous intensity [197] and minimize error in estimating the length of bouts of moderate-vigorous activity [341]. The cut-points specified also modify the amount of time calculated as moderate-vigorous intensity [316]. Actical and Actigraph provide thresholds with the manufacturer software, which are predominantly used by researchers to classify intensity of physical activity.

The purpose of this study was to measure children's physical activity in home and school settings and determine the magnitude of difference in physical activity levels when different sampling intervals and cut-points were applied to accelerometer data. In the present study, we divided school and weekend days into time periods that contribute to daily activity levels and compared the estimates provided by continuous accelerometer recordings analysed in three ways: i) using the manufacturer's settings for intensity thresholds and sampling interval (60 s), and ii) using intensity thresholds of Puyau et al. [217] with 60-s and iii) Puyau et al. [217] with 15-s sampling intervals.

METHODS

Participants

Two primary schools in Auckland, New Zealand, granted consent to participate in the study and 79 of the 120 eligible children (41 boys and 38 girls; age 9.7 ± 0.36) from seven classes volunteered and returned signed informed consent and assent forms. The two participating schools were located in North Shore (Auckland); each school provided 3 x 30 min physical education classes per week, and 30 min morning play and 60 min lunch breaks.

New Zealand has a decile rating system to determine the extent of additional educational funding. The participating schools were on the sixth decile, where the tenth decile is the highest socio-economic status. The ethnic proportions of the participants and of the New Zealand population[288] indicated in brackets were: European 63.3% (67.6%), Asian 17.7% (9.2%), Maori 7.6% (14.6%), African 5.1% (0.9%), Pacific Islanders 3.8% (6.9%), other 2.6% (0.8%).

Study design

Two weekend and five school days of 15 s accelerometer count data were collected before implementing a play intervention during winter and spring, July and October 2007. Sport and Recreation New Zealand and SPSS New Zealand Ltd provided play equipment but had no involvement in the study design; collection, analysis, or interpretation of data; or the decision to publish. The children also wore pedometers to provide an additional measure of physical activity for comparison with the estimates provided by the accelerometer. The study was approved by the AUT university ethics committee.

Instruments

Accelerometer

Children's height and weight were measured using a portable stadiometer (Design No. 1013522, Surgical and Medical Products, Seven Hills, Australia) and digital scales (Model Seca 770, Seca, Hamburg, Germany) according to the ISAK protocols. Accelerometers and pedometers were attached to elastic belts and fitted so that the monitors were located above the right hip bone. Children were required to demonstrate competency in removal and fitting of the monitors. The children were instructed to remove the accelerometer when bathing or swimming and just prior to retiring for bed and to refit the accelerometer on waking. Logs of non-wearing times were not kept, as children's self report logs are unreliable, and in a recent study there was little mismatch between non-wearing times estimated from logs and accelerometers [330]. The accelerometers were the omni-directional water-resistant Actical (Mini-Mitter Co., Inc., Bend, OR). Actical accelerometers had the best intra- and inter-instrument reliability compared to Actigraph (7164) and AMP-331 monitors when tested using a mechanical laboratory setup [320]. The Actical monitor uses a peizo-electric sensor and a sampling frequency of 32 Hz that is capable of differentiating rapid body movements typical of children's walking and running (1.75-3.5 Hz) [271]. The Actical measures accelerations in the range of 0.05-2.0 g that detects children's accelerations accurately during running (1.3 g), fast (0.5 g) and slow walking (0.2 g) but not jumping (2.5 g) [284]. The pedometers were multi-day-memory pedometers (Model NL-2000, New Lifestyles Inc., Lee's Summit, MO) that use a peizo-electric strain gauge to count steps.

Thresholds

Children's activity was assessed using the manufacturer's thresholds with those developed for the Actical monitor by Puyau et al. [217], which account for higher basal metabolic rates observed in children. Actical 2.04 adolescent thresholds were derived by Heil [334]; a description of the application of the regression equations is provided in Crouter et al. [342].

Sampling interval

Nilsson et al. [340] proposed that 5- or 10-s sampling intervals are ideal for accurate determination of children's vigorous activity. The Actical has a minimum sampling interval of 15 s, which is consistent with the mean duration of children's physical activity bouts of ~20 s across all intensities [329]. Compared to using sampling intervals of 5 s, intervals of 15 s misclassifies ~8 $min \cdot d^{-1}$ vigorous activity as moderate [197]. We compared Actical-classified activity using 60-s sampling intervals with activity categorised using Puyau et al. [217] thresholds with 60- and 15-s sampling intervals.

Data reduction

Accelerometer data were exported from Actical “1R” (single regression) files. School days were divided into time spent in four settings class, recess, commuting and home. To determine the total time accelerometers were worn, accelerometer counts during children’s normal sleep times (23:00-06:00) were excluded and the first non-zero count after 06:00 and the last non-zero count before 23:00 was used to designate the start and end time accelerometers were worn. Most children wore accelerometers during winter daylight hours (07:00-18:00) so this time period was used to define the standard school day. Each day ~20% of data were removed from analysis if accelerometers were worn for <9 h during 07:00-18:00, or the total accelerometer count for the day was implausibly high (>700,000) or low (<70,000) indicating a faulty accelerometer. Researchers have determined accelerometer non-wearing times as periods of continuous zeros ranging from 10-180 min [322]. We found periods of continuous zeros exceeding 60 min during class time, so we opted for a period of >120 min to represent non-wearing.

Statistical analysis

Analyses were performed in the Statistical Analysis System (Version 9.1, SAS Institute, Cary, NC) using Proc Mixed. The dependent variable was the proportion of time spent at a given intensity in each daily setting. The arcsine-root transformation produced uniform errors across all intervals. Estimates were back transformed and expressed as percents of time spent at different intensities in each setting. Puyau et al. [217] thresholds and sampling intervals of 15 and 60 s were applied to children’s accelerometer data for comparison with activity classified by Actical thresholds and 60-s intervals. Any slight mismatch between the back transformed effects and the differences in the means arising from the use of the non-linear arcsine root transformation were adjusted so that time spent in different intensities and settings totaled 100%. Inferences were based on standardised magnitude thresholds (0.0 - trivial; 0.2 – small; 0.6 – moderate; 1.2 – large; 2.0 - very large) [220] using 1000 bootstrap samples; uncertainty in effects was expressed as 90% confidence intervals. If the 90% confidence interval overlapped zero it was uncertain whether the effect could be substantially positive or negative so the effect was deemed unclear; other effects were clear.

RESULTS

Participant characteristics

Descriptive characteristics of participants are shown in Table 7.1. Participants were excluded from the final data set due to faulty accelerometers (13), participant withdrawals (2), absenteeism (2), lost accelerometers (1) and children changing school (1). Of the 38 girls and 41 boys in the final analysis, 36 and 38 provided data for the winter week, while 33 and 32 provided data in the spring week.

Table 7.1. Descriptive statistics (mean ± SD) of study participants by gender.

	Female (n=38)	Male (n=41)
Age (y)	9.4 ± 0.4	9.8 ± 0.4
Weight (kg)	34.2 ± 6.1	36.3 ± 7.1
Height (cm)	137.7 ± 6.3	137.4 ± 6.7
BMI ($kg \cdot m^{-2}$)	17.9 ± 2.8	19.1 ± 2.8
Weekday step count (x1000)	14.3 ± 4.2	16.2 ± 3.8
Weekend day step count (x1000)	10.2 ± 5.5	11.8 ± 6.8

Table 7.2 summarises percentage of time children spent in activity intensities using thresholds calculated by the Actical software and Puyau thresholds. The most noteworthy result is the very large difference in moderate activity between manufacturer and Puyau 60-s thresholds.

Table 7.2. Weekly percentage of time spent in sedentary, light, moderate and vigorous activity in boys and girls estimated by the three classification methods; differences between the methods are shown with confidence intervals and magnitudes.

		Puyau 15-s	Puyau 60-s	Actical	Puyau 60-s vs. Puyau 15-s		Actical vs. Puyau 60-s	
			Mean ± SD		Mean; 90%CI	Magnitude	Mean; 90%CI	Magnitude
Sedentary	Girls	74 ± 10	67 ± 12	50 ± 16	-7.5; -8.0 to -6.9	moderate ↓	-19; -20 to -18	large ↓
	Boys	74 ± 9	68 ± 11	52 ± 14	-7.3; -7.7 to -6.9	moderate ↓	-17; -17 to -17	large ↓
Light	Girls	21 ± 7	28 ± 9	33 ± 10	6.8; 6.3 to 7.5	moderate ↑	3.4; 2.5 to 4.4	small ↑
	Boys	20 ± 6	27 ± 8	30 ± 7	5.7; 5.3 to 6.1	moderate ↑	2.3; 1.6 to 3.0	small ↑
Moderate	Girls	4.9 ± 2.4	4.6 ± 3.2	16.9 ± 7.1	-0.4; -0.7 to 0.0	trivial ↓	11; 10 to 12	very large ↑
	Boys	5.3 ± 2.7	5.0 ± 3.0	17.6 ± 7.2	-0.4; -0.5 to -0.2	trivial ↓	11; 11 to 12	very large ↑
Vigorous	Girls	0.21 ± 0.21	0.00 ± 0.10	0.11 ± 0.11	-0.17; -0.19 to -0.15	moderate ↓	0.07; 0.04 to 0.09	small ↑
	Boys	0.31 ± 0.31	0.00 ± 0.11	0.22 ± 0.22	-0.23; -0.24 to -0.22	large ↓	0.10; 0.09 to 0.12	moderate ↑

Magnitudes were determined by standardization. ↑ = increase, ↓= decrease.

Figure 7.1 summarises activity durations estimated by the three classification methods for total weekday and weekend days and various periods during weekdays. Activity during class time included physical education, outdoor education, walking between classrooms, and any movement during lessons. Observations during the present study revealed that children normally commuted to school 08:00-09:00 and travelled back home 15:00-15:30; consequently commuting time included all activity accrued during these times. The differences between activity profiles for boys and girls during recess and commuting were moderate, and in all other periods the differences in sedentary, light, moderate and vigorous activity were small or trivial.

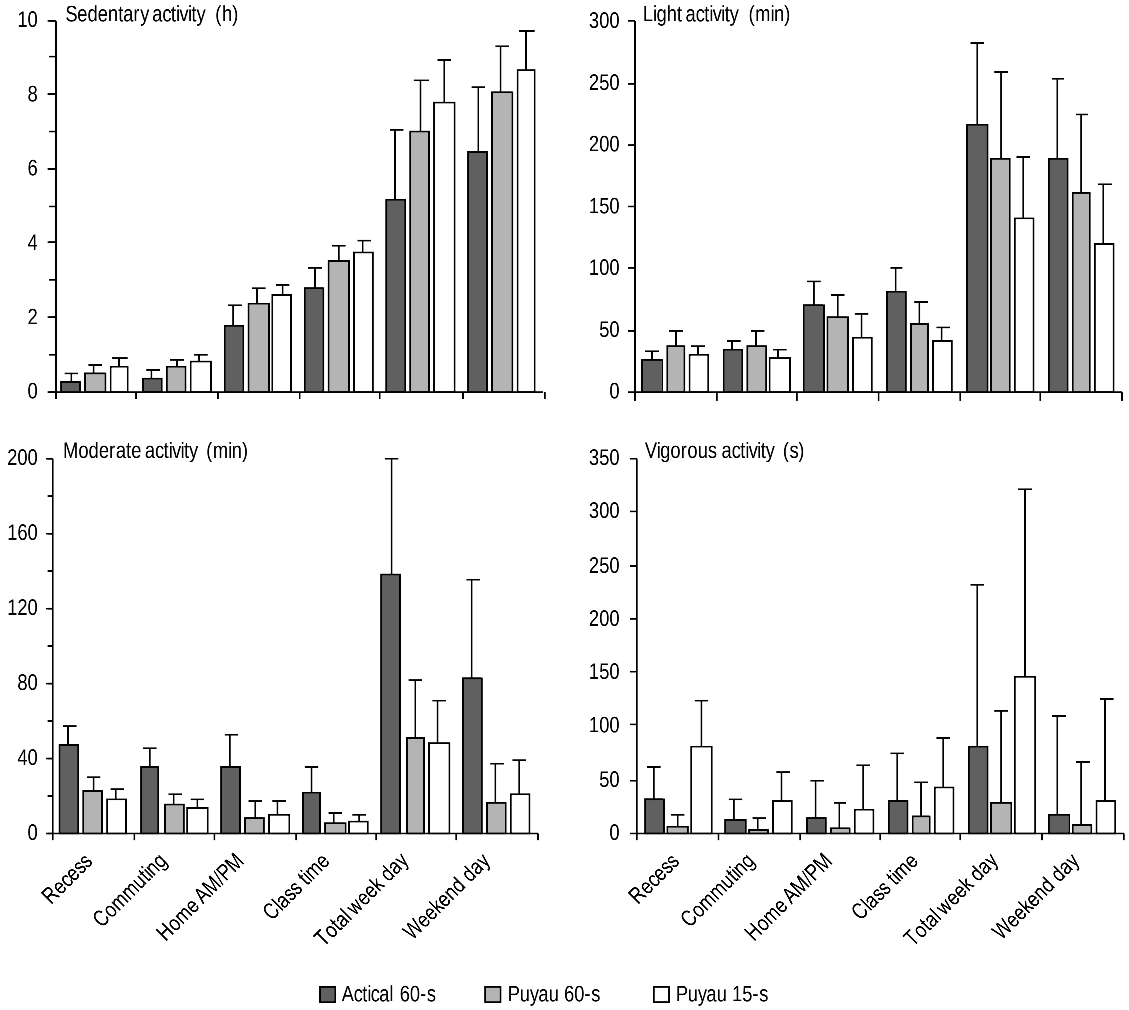


Figure 7.1. Time children (boys and girls combined) spent in sedentary, light, moderate and vigorous activity in different settings 07:00 to 18:00.
Data are means; error bars are standard deviations.

To determine how Actical applied the energy expenditure thresholds to accelerometer counts, we reviewed the Actical export files of each child. The energy expenditure thresholds of 0.01, 0.04 and 0.10 $kcal \cdot kg^{-1} \cdot min^{-1}$ set by Actical (for light, moderate and vigorous, respectively) classified counts of >5188 as vigorous intensity, 464-5188 as moderate, and 150-463 as light. Counts of 0-149 following an activity bout were classified as sedentary or light by software algorithms according to the count and intensity category of the preceding interval(s). If the preceding interval was classified as sedentary and the current interval count was <150, software classified the current interval as sedentary. If consecutive non-zero intervals <150 (i.e., two consecutive sedentary intervals) summed to a value >150 an algorithm would classify the last consecutive non-zero interval as light. If the preceding interval accelerometer count was 150-349 (light) and the current interval was <150 (sedentary), software would classify the current interval as light. Following each bout of moderate or vigorous activity, software classified two consecutive intervals with counts <150 (sedentary) as light intensity.

DISCUSSION

This is the first accelerometer study of New Zealand primary school children to evaluate the contribution of activity accumulated in different settings on school days and simultaneously analyse the effect of threshold and sampling interval. In each setting, there were small to large clear differences in time spent at different activity intensities, depending on whether manufacturer or published intensity thresholds were used. There were also substantial effects for shorter sampling intervals at all intensities except moderate. We have also found substantial differences in the proportions of children that met daily physical activity recommendations assessed by pedometer steps [218] and accelerometer derived moderate-vigorous activity.

The present study identified that children accrued ~60-75% of daily moderate and ~25-75% vigorous activity during recess and commuting to school. Also, on school days children engaged in ~1.5-3 times more moderate and ~4-5 times as much vigorous activity compared to weekend days. The finding of lower activity during weekends is consistent with pedometer [140, 343] and accelerometer studies [344-345] but not all previous research [346]. Play during class breaks was clearly the greatest contributor to higher intensity activity even though children were obligated to spend 10 minutes sitting eating lunch. Commuting was the next most important time period for children to accumulate daily recommended activity. Activity during class lessons was similar to activity patterns at home. A recent study [249] found that only 15 minutes a day is spent playing outside at home, which equates to the time children spent outdoors in physical education classes, potentially explaining the similarity between indoor class-time activity and activity indoors at home.

In every setting the difference in time spent in moderate and vigorous activity is attributable to the different thresholds used by the manufacturer and those of Puyau et al. [217]. Mean accelerometer counts of 5368 [334] and 4664 [217] were achieved during vigorous walking (>6 MET); consequently the Actical threshold of >5188 may better capture the transition to vigorous intensity. The three-fold increase in time spent in moderate activity determined by Actical vs. Puyau thresholds is the result of the different light-moderate threshold of 464 used by the manufacturer and 1500 derived by Puyau et al. [217]. The Actical light thresholds of 150-463 counts should classify less activity as light than the Puyau et al. [217] thresholds of 100-1499. Nevertheless, Actical algorithms classified sedentary activity (counts <150) following each activity bout as light intensity thereby increasing light activity by ~2 $h \cdot d^{-1}$. The manufacturer's attempt to account for post-activity energy expenditure is commendable, but there appears to be no published justification for this approach.

The greatest effect of 15 s compared with 60 s sampling intervals was to capture ~5 times more weekday vigorous activity (Figure 7.1). A recent study that combined weekend and weekday activity reported only ~1.6 times increased vigorous activity for the same reduction in interval [197]. Another important finding of this study was that decreasing the sampling interval had little effect on moderate activity probably because children's moderate bouts typically last 5 min or longer [345]. Shorter sampling intervals also increased the time classified as sedentary and decreased light activity, which is consistent with a study of children in England [197].

Participants in the current study were measured in free-living conditions precluding the use of a criterion measure such as indirect calorimetry to validate threshold intensity. To interpret the suitability of intensity thresholds, we assessed compliance with activity guidelines using pedometer data and accelerometer estimates of moderate-vigorous activity from the current study. Published rather than manufacturer thresholds were in better agreement with the percentage of children that met daily recommended pedometer steps [218]. The lower threshold set by Actical may be overestimating moderate activity levels by classifying light activity as moderate similar to the outcome in a recent study [316].

A limitation of this study could be the way Puyau 15-s thresholds were determined, by dividing Puyau 60-s thresholds by four. Another limitation arises from applying single linear regression equations to accelerometer data to differentiate activity intensity because participant energy expenditure varies according to body mass [347], fitness [348], basal metabolic rate [217] and VO_2 response to exercise [349]. In addition, we did not determine which decision rules was the most accurate estimate of physical activity as it was not within the scope of this study. A validation study focusing on this aspect will need to be conducted separately.

CONCLUSIONS

In summary, the key finding of this study is that time spent in different activity intensities differed substantially when published thresholds from calibration studies were used rather than manufacturer thresholds. Researchers should use thresholds determined by a calibration study. In agreement with other studies, shorter sampling intervals classified children's sedentary, light and vigorous activity more realistically. The school environment is an important setting for New Zealand primary school children to accumulate activity to meet public health physical activity recommendations. The outdoor free-play opportunities during play-breaks and physical activity associated with school travel were the major contributors to children's weekly moderate and vigorous activity.

Acknowledgements

The authors thank the children, parents and schools that participated in this study, Purvi Chhichhia who was essential for collecting the data, and Sport and Recreation New Zealand and SPSS New Zealand Ltd who assisted with the provision of children's play equipment.

CHAPTER 8: GENERAL DISCUSSION: EVALUATING URBAN ENVIRONMENTS FOR CHILDREN'S ACTIVITY

This thesis was undertaken to investigate the effects of the built environment on children’s habitual activity and to address issues with measuring physical activity. The findings of the thesis studies and the implications for neighbourhood design are summarised and discussed here.

In Chapters 2 and 3 a relationship emerged between built environment effects on children’s physical activity associated with danger from vehicular traffic. Objectively measured built environments had consistent positive or negative effects on children’s objectively measured activity that depended on whether the environment was conducive for safe walking and play. The quantity of traffic infrastructure in the local neighbourhood was apparently associated with parents’ decision to deny or grant permission for children to roam and play child safety [257]. Urban planners provide additional neighbourhood traffic infrastructure on the basis of higher traffic volumes [290], so it would seem that the parental decision to allow or constrain activity was in part based on traffic volumes. Parents may also assess their child’s ability to avoid vehicular collisions and use that assessment to determine the boundary of free roaming, which may be limited to the backyard or cul-de-sac [257]. Parental traffic concerns are rational, because children’s risk of vehicle-pedestrian collision are four times higher than that of adults, which has been linked to children’s under-developed visual perception that identifies fast (>30 km/h) approaching vehicles as stationary [293, 350].

Traffic infrastructure and safety provide a reasonable explanation for the negative effects of walkability on children's activity in Chapters 2 and 3. Neighbourhoods that were identified as highly walkable in Chapter 2 had positive effects on adolescent’s activity. Walkability is quantified for adults and seems suitable for predicting adolescent's but not children's activity. Urban planners and city developers have already been considering designs that make neighbourhoods more pedestrian friendly [296-297]. In Chapter 3 it became apparent that "pedestrian friendly" was a concept based on how adults safely navigate vehicle traffic without due consideration to construct a pedestrian environment suitable for children. Urban planners and researchers have been investigating some innovative pedestrian-safety strategies for use in school zones mostly designed to alert drivers that pedestrians are crossing roads, to reduce traffic speed and decrease braking distance [296-297]. Unfortunately, these strategies are unlikely to reduce traffic volumes during school travel times, which are associated with elevated road accident rates [351]. In Chapter 3 the provision of pedestrian infrastructure had negative effects on physical activity presumably because parents are making judgments as to whether their child is safe when crossing the road [293, 350]. Pneumatic bollards that are activated when children cross at pedestrian crossings are now appearing in some cities (e.g., New York) and may provide a cost effective solution to avoid vehicle-pedestrian collisions [352]. One traffic-safety strategy that is focused on improving neighbourhood walkability is the use of non-traffic walkways to link cul-de-sacs, parks, schools and shopping centres [297], which could potentially increase active commuting [113].

Play areas were one aspect of the built environment that had positive effects on children's physical activity in Chapters 2 and 3. Traffic safety could explain at least part of this relationship, because play areas are generally isolated from traffic. Studies in Chapter 2 that used GPS technology to track where children were active in the built environment revealed that non-green urban spaces such as empty car parks are being utilized as areas for children to play [233, 249-250, 266, 268]. Researchers tend not to highlight the fact that unconventional urban settings are also important places where children can play and be physically active, which may be an important consideration for urban design. A key finding from Chapter 3 consistent with evidence presented in Chapter 2 is that recreational green space, sports fields and beaches in close proximity to children's residences increase habitual physical activity [233, 249, 266, 268]. Collectively these findings support the notion that residential areas in cities have to be designed to be "pedestrian and play friendly", by providing places that children can walk to and play in either green or non-green spaces.

Street-audits were used to assess traffic infrastructure in Chapter 3, but audits require researchers to visit neighbourhoods personally and are unsuitable for use with data on children's locations obtained with GPS technology [233]. GIS analysis, which is based on local authority records, could also have been used to map traffic infrastructure locations, along with topography, vegetation and other built-environment measures [226, 231-232]. Studies reviewed in Chapter 1 have already combined GPS with accelerometry to track mobility within the GIS-mapped neighbourhoods [234-235], but limitations in GPS technology have restricted the quality of data collected and traffic data were not included [226, 231-232]. Adding traffic information such as vehicle-pedestrian collision data into GIS maps overlaid with children's GPS-mobility data may provide valuable insights about traffic-danger, avoidance strategies near busier streets and highlight design elements that make urban areas safer [231]. There have been significant advances in GPS technology that will benefit these types of research, especially with the latest low-power consumption SiRFstarV receivers that provide location data even when satellite reception is blocked. Constructing comprehensive GIS neighbourhood maps overlaid with mobility data [234-235] from newer GPS watches has the potential to provide activity data in shopping malls and other indoor locations previously undefined in research.

In Chapter 4 factors potentially affecting children's activity moved from the built environment to more general features of the environment, including weather and darkness. A novel aspect of this study was use of accelerometer steps to quantify activity, so effects of basic demographic characteristics (gender, age, ethnicity, body-mass index) as well as differences between school days and non-school days were included. The main findings were that reductions in step activity occurred when environmental conditions darkness, rainfall and temperature became unfavourable for activity. There were also more total and moderate-vigorous steps during school hours arising from travel and play.

In Chapters 2 and 3 it was identified that the built environment may indirectly confine children's independent roaming and playing to indoor areas, backyards or cul-de-sacs [233, 249, 266-267]. To combat the effects of higher-density living as cities become more modernised it is important to develop moderate-vigorous intensity indoor and outdoor games suitable for confined spaces. The objective of interventions designed to increase children's moderate-vigorous physical activity is to decrease childhood obesity by increasing daily energy expenditure. Children were more active on school days in Chapters 3 and 4, which suggest that on non-school days children are limited to or are self-selecting lower intensity activities [99]. In Chapter 5 an intervention promoting supervised unstructured play before school (08:00-09:00) and free access to play equipment to cultivate children's habit to self-determine higher intensity activity through play. The intervention had unclear effects on physical activity, but the expected increases in children's body-mass index did not occur, and there was even the possibility of a small reduction in girls' body-mass index. Children's body-mass index increases with age as a normal consequence of growth so trivial reductions or maintenance of body-mass index can be considered a successful outcome [323-324]. In order to detect clear intervention effects on physical activity, larger sample sizes and more sophisticated statistical methods are required, like those used in Chapters 3 and 4, that adjust for weather and other confounders.

Data loss from failure to wear the accelerometers or failure of the accelerometer to work properly emerged as an important issue in Chapter 2 and during the analysis of intervention effects in Chapter 5. A more detailed analysis of the data loss was therefore undertaken in Chapter 6. Only one fifth of children had seven days of activity data for each of the four weeks of recording, and after exclusion for data loss only 50% of children provided activity data for analysis. Reasons for data loss were that children mostly forgot to wear accelerometers, wearing accelerometers was uncomfortable, and many accelerometers were faulty. Over the data collection period a set of protocols was developed to identify faulty accelerometers before going into the field, and in Chapters 3 and 4 data lost from faulty monitors was less than 0.5%. In hindsight the instruction to remove accelerometers during sleep contributed unnecessarily to data loss, as accelerometers are worn during research on sleep. The Actical monitor is sufficiently waterproof for bathing and provides valid activity data when worn on the wrist, so it is feasible for children to wear the accelerometers continuously [334]. The newer Actigraph and GENEA models are also waterproof and provide valid activity data when worn on the wrist [212, 353-354]. Accelerometer watches could reduce participant burden by replacing uncomfortable accelerometer belts and improve compliance by wearing the device continuously thus reducing missing data [212, 353-354]. In addition, with a continuous recording of data there would be fewer biases arising from missing data [220].

Decisions made about built-environment effects on children's habitual physical activity are influenced by the choice of intensity thresholds. In Chapter 2 the accelerometer count used to define moderate-vigorous intensity ranged from 800-3200, even though children’s age was similar, which must produce differences in the time spent at moderate-vigorous intensity. The recording epoch is also a related issue, because short duration activity at higher intensity is averaged to lower intensity activity with longer epochs (e.g., 10 s of moderate activity followed by 50 s of rest is averaged to light activity with 60 s epochs). The data recorded in Chapter 5 offered an opportunity to investigate these issues. In Chapter 7 the effects of intensity thresholds and sampling interval were investigated and it was found that moderate activity showed little effect of interval but very large effects of threshold. Consequently, there were major effects of threshold on the proportion of children meeting moderate-vigorous physical activity guidelines. It is apparent from the wide range in the counts used to define the level of moderate activity in Chapter 2 that researchers have not reached a consensus yet on the appropriate threshold to use with Actigraph accelerometers. Accelerometers measure acceleration (g) as accelerometer counts associated with ground reaction forces occurring during walking, running and jumping and accelerometer counts are used to estimate energy expenditure (MET) [353-354]. Therefore, to ensure some comparability between data provided from different accelerometer brands and models, researchers should report accelerometer counts and acceleration values (g) for each MET threshold. In the meantime, in Chapter 2 it was found that expressing effects as standardized magnitudes eliminated apparent inconsistencies in effects arising from the use of different thresholds.

Limitations and delimitations

The following limitations of this thesis are acknowledged. Although the Actical accelerometer is capable of measuring both steps and intensity of activity the device memory size limited the sampling intervals used in the thesis to 15- or 30- s and 5-10 s are required to accurately capture vigorous intensity activity [340]. Future studies using accelerometers to evaluate children's patterns of activity should use shorter sampling intervals (5- or 10- s) to provide a more detailed analysis of transitions between higher intensity activity (e.g. running) and lower intensity activity (e.g. walking or rest). The use of quantiles to determine whether there are non-linear effects of built environment variables on children's physical activity produce arbitrary cut-points between the tertiles of the variable and are a limitation [223]. Although quantiles are useful in the preliminary assessment of the relationship between built environment variables and physical activity it is recommended that in future research these relationships are modelled directly using non-linear terms [223]. An overall delimitation was the time taken to collect and analyse the data, which precluded other analyses of data collected during the thesis including parent's perceptions of the built environment and the validity of the Actical step-count function.

In Chapter 3 the cross-sectional nature of study and absence of objective activity-location data means that it is difficult to make causal inferences about built-environment characteristics and children's physical activity. A potential limitation of the study in Chapter 4 is that localized rainfall and temperature experienced by participants may have differed from the temperature and rainfall data collected at fixed weather stations. Also in Chapter 4 the effect of extreme cold or hot ambient temperatures experienced in other countries could not be investigated. The effect of providing incentives on the percentage of children wearing accelerometers in Chapter 5 and 6 was unclear, as the effect of compliance strategies was not systematically investigated. The accelerometer field preparation suggested in Chapter 6 does not replace accelerometer calibration with a mechanical shaker rather the intention was to prevent obviously faulty accelerometers from being provided to participants.

Future directions

Several possibilities for improvement in methodology for studies of children's activity became apparent during the course of the research for this thesis. In particular the following recommendations are suggested.

- Researchers should express effects on physical activity as standardized magnitudes to eliminate apparent inconsistencies in effects arising from the use of different moderate-vigorous thresholds.
- MET thresholds used to define activity intensity should be reported with the threshold accelerometer count and acceleration value (g).
- Studies investigating walkability should report physical activity in steps preferably with light, moderate-vigorous and total steps.
- Built-environment studies with child participants should include traffic information in the neighbourhood GIS analysis.

Specific future research projects should include:

- Studies to test the accuracy of GPS watches that use the SiRFstarV receiver that provide continuous indoor location and physical activity data.
- Studies to determine whether GPS and accelerometer watches can increase compliance and reduce participant burden for children and adolescents.
- Joint parent-child studies with GPS and accelerometry to determine dependent and independent roaming in the built-environment.

- Collaborative research with urban designers to test the effect of new residential neighbourhood designs and modified pedestrian environments on children's activity.
- Intervention studies that use moderate-vigorous intensity indoor games suitable to be played in confined areas to increase children's activity.
- Studies to investigate the effects of traffic-danger on children's activity should use GIS neighbourhood maps that include traffic volume, vehicle-pedestrian collisions and traffic infrastructure. Children's GPS-defined dependent and independent mobility can be overlaid on the GIS maps to understand the neighbourhood features that define safe and unsafe areas.

CONCLUSIONS

The overall conclusions from this thesis are outlined below and illustrated in Figure 8.3. The local environments that are suitable for children to roam and play in freely have less traffic infrastructure on attractive streets with safe places for children to play in parks, playgrounds, sports fields and other urban spaces. The greatest barrier to children's independent mobility and play is danger from traffic. Modifying urban environments to provide neighbourhood play spaces and pedestrian networks that are either traffic-free or have design elements that prevent or drastically reduce vehicle-pedestrian collisions will provide a children's physical activity intervention that is enduring.

Chapter One

Introduction: Intervening to increase children's daily activity

Aim: To review the general literature, and identify research directions and issues.

Question: Why intervene to increase children's daily physical activity?

Conclusion: Obesity has substantial negative effects on health [1-3]. Preventing weight gain is more effective than treating obesity once it has developed[1-3] yet interventions to increase physical activity and improve nutrition have produced negligible to small effects on reducing body-mass index. The environment is postulated to contribute greatly to the obesity pandemic[5]. Yet research to date has not clearly identified which changes to the environment account for lower physical activity that contributes to childhood obesity. The neighbourhood environment has the potential to affect the long-term health[6-7]. Understanding which environmental variables contribute to children's routine physical activity will provide evidence of what to modify in the environment to increase children's activity.

Chapter Two

Effect of the built environment on children's moderate-vigorous physical activity

Aim: To review studies linking aspects of the built environment with children's moderate-vigorous physical activity

Question: What is currently known about effects of the built environment on children's physical activity?

Conclusion: Built environments have substantial positive effects on time children habitually spent performing moderate-vigorous activity mostly through opportunities provided by having local places to play, walkable neighbourhood streets and less dangerous traffic. The differences in urbanisation between rural, suburban and metropolitan centres did not predict children's daily activity. Parents are crucial in determining children's physical activity by either constraining or facilitating activity. Children with permission seize opportunities to be active in all types of built-environment settings.

Chapter Three

Effects of neighborhood infrastructure on physical activity in New Zealand children

Aim: To determine the strength of associations between GIS measures of the residential neighbourhood and children's physical activity.

Question: What built environmental features predict New Zealand children's habitual physical activity?

Conclusion: The built environment had clear substantial positive effects on children's physical activity when there was a reasonable distance to walk to school, there were safe attractive streets to walk along, or in neighborhoods more conducive for safe play, in low-density housing areas, close to a school, or those with nearby green space, beaches or sports grounds. Children's non-school hour activity decreased in more urbanised neighborhoods near commercial centres, with higher traffic danger or less play space.

↓

Chapter Four

Children's step counts at light and moderate-vigorous intensities during school and non-school days

Aim: To determine the effect of meteorological variables on children's steps accumulated at light and moderate-to-vigorous intensity

Question: What are the effects of darkness, rainfall, and temperature on children's physical activity?

What proportions of children's steps are accumulated at different intensities on school and non-school days?

↓

Conclusion: Steps at moderate-vigorous intensity were accumulated at a mean cadence of ~80 step counts•min^{-1} and accounted for a quarter of school-day total steps and a fifth of holiday-day steps. Children's step activity was greatest during school playtime and travel to and from school. Onset of evening darkness, days colder by 10 ºC, and daily rainfall ≥1 mm, respectively accounted for small-large, small, and trivial-small decreases in step activity. Factors that affect activity are more identifiable when children can self-determine physical activity during non-school days. Promotion of walking, outdoor and indoor active play is needed to offset lower step activity that occurs during unfavourable environmental conditions or on non-school days, when children have more freedom to self-select activities.

↓

Chapter Five

Power of Play: A Primary School Intervention to increase physical activity in New Zealand children

Aim: To implement an intervention to increase children's physical activity by providing play and sport equipment for children to engage in self-directed play before school and during class breaks.

Question: Is a play intervention at school a short-to-medium term solution to increasing physical activity in New Zealand children?

↓

Conclusion: There were reductions in girls' body-mass index but the effect was trivial. Body-mass index of boys receiving the intervention remained constant. Children that provided accelerometer data for each repeated measure had small reductions in moderate to vigorous activity. The measured physical activity is not consistent with the positive effects on children's body-mass index. The effects on body-mass index may better indicate the overall effect of the intervention and warrant further investigation.

Chapter Six

Examining loss of activity data in accelerometer studies with children

Aim: To examine reasons for children's non-compliance and other factors that affect data loss in accelerometer studies.

Question: What factors affect the proportions of valid physical activity data in children's accelerometer studies?

Conclusion: Half of children's results were omitted from analysis as a consequence of children not wearing the monitors for sufficient hours of the day or days per week (22%), faulty and lost monitors accounted for 14% of data loss while 13% of children did not remain in the study long term. Many children reported discomfort when wearing the monitor. Mandatory quality control checks of monitor functionality and increased sample size are recommended for intervention studies. To increase compliance, researchers should invest in motion sensors that are comfortable to wear continuously, detect wear time and are less prone to failure.

Chapter Seven

Accelerometer sampling interval and intensity thresholds effect on measures of children's physical activity

Aim: To compare children's physical activity using different thresholds and sampling intervals.

Question: How do children's proportions of time at different activity intensities compare when using manufacturer thresholds at 60-s intervals, with thresholds of Puyau and colleagues at 60-s and 15-s intervals?

Conclusion: Time spent in different activity intensities differed substantially when published thresholds from calibration studies were used rather than manufacturer thresholds. Researchers should use thresholds determined by a calibration study. In agreement with other studies, shorter sampling intervals classified children's sedentary, light and vigorous activity more realistically.

Figure 8.1. The results and conclusions of the thesis.

REFERENCES

1 Basdevant A, Boute D, Borys JM. Who should be educated? Education strategies: could children educate their parents? *Int J Obes Relat Metab Disord*. 1999; **23 Suppl 4**: S10-2; discussion S12-3.

2 Harrell JS, Gansky SA, McMurray RG, Bangdiwala SI, Frauman AC, Bradley CB. School-based interventions improve heart health in children with multiple cardiovascular disease risk factors. *Pediatrics*. 1998; **102**: 371-80.

3 Zwiauer KF. Prevention and treatment of overweight and obesity in children and adolescents. *Eur J Pediatr*. 2000; **159 Suppl 1**: S56-68.

4 Sallis JF, Cervero RB, Ascher W, Henderson KA, Kraft MK, Kerr J. An ecological approach to creating active living communities. *Annu Rev Public Health*. 2006; **27**: 297-322.

5 Hill JO, Peters JC. Environmental contributions to the obesity epidemic. *Science*. 1998; **280**: 1371-4.

6 Sallis JF, Glanz K. The role of built environments in physical activity, eating, and obesity in childhood. *Future Child*. 2006; **16**: 89-108.

7 Giles-Corti B, Kelty SF, Zubrick SR, Villanueva KP. Encouraging walking for transport and physical activity in children and adolescents: how important is the built environment? *Sports Med*. 2009; **39**: 995-1009.

8 WHO. Global recommendations on physical activity for health. World Health Organisation, Geneva, 2010; 1-60.

9 Janssen I, Katzmarzyk PT, Srinivasan SR, Chen W, Malina RM, Bouchard C, *et al.* Utility of childhood BMI in the prediction of adulthood disease: comparison of national and international references. *Obes Res*. 2005; **13**: 1106-15.

10 Dietz WH. Health consequences of obesity in youth: childhood predictors of adult disease. *Pediatrics*. 1998; **101**: 518-25.

11 Powell KE, Blair SN. The public health burdens of sedentary living habits: theoretical but realistic estimates. *Med Sci Sports Exerc*. 1994; **26**: 851-6.

12 Turnbull A, Barry D, Wickens K, Crane J. Changes in body mass index in 11-12-year-old children in Hawkes Bay, New Zealand (1989-2000). *J Paediatr Child Health*. 2004; **40**: 33-7.

13 Craig E, Taufa S, Jackson C, Yeo Han D. The Health of Pacific Children and Young People in New Zealand. Ministry of Health, Auckland, 2008.

14 Willms JD, Tremblay MS, Katzmarzyk PT. Geographic and demographic variation in the prevalence of overweight Canadian children. *Obes Res*. 2003; **11**: 668-73.

15 Booth ML, Chey T, Wake M, Norton K, Hesketh K, Dollman J, *et al.* Change in the prevalence of overweight and obesity among young Australians, 1969-1997. *Am J Clin Nutr*. 2003; **77**: 29-36.

16 Willms JD. Early childhood obesity: a call for early surveillance and preventive measures. *CMAJ*. 2004; **171**: 243-4.

17 Andersen LB, Hasselstrom H, Gronfeldt V, Hansen SE, Karsten F. The relationship between physical fitness and clustered risk, and tracking of clustered risk from adolescence to young adulthood: eight years follow-up in the Danish Youth and Sport Study. *Int J Behav Nutr Phys Act*. 2004; **1**: 6.

18 Whitaker RC, Wright JA, Pepe MS, Seidel KD, Dietz WH. Predicting obesity in young adulthood from childhood and parental obesity. *N Engl J Med*. 1997; **337**: 869-73.

19 Mathers C, Stevens G, Mascarenhas M. Global health risks: mortality and burden of disease attributable to selected major risks. World Health

Organization, Geneva, 2009.
20 Kylin E. Studien Hypertonie – Hyperglykamie – Hyperurikamie syndrome. *Zentralblatt fur innere Medizin*. 1923; **44**.
21 Himsworth HP. The mechanism of diabetes mellitus. I. *Lancet*. 1939; **2**: 1-6.
22 Himsworth HP. The mechanism of diabetes mellitus. II. The control of the blood sugar level. *Lancet*. 1939; **2**: 65-68.
23 Himsworth HP. The mechanism of diabetes mellitus. II. The control of the blood sugar level (cont). *Lancet*. 1939; **2**.
24 Himsworth HP. The mechanism of diabetes mellitus. III. Human diabetes mellitus. *Lancet*. 1939; **2**: 171-75.
25 Vague J. La differenciation, sexuelle facteur determinant des formes de l'obesite. *La Presse Medicale*. 1947; **55**: 339-440.
26 Albrink MJ, Fitzgerald JR, Man EB. Reduction of alimentary lipemia by glucose. *Metabolism*. 1958; **7**: 162-71.
27 Albrink MJ, Mann EB. Serum triglycerides in coronary artery disease. *Trans Assoc Am Physicians*. 1958; **71**: 162-73.
28 Atabek ME, Pirgon O, Kurtoglu S. Prevalence of metabolic syndrome in obese Turkish children and adolescents. *Diabetes Res Clin Pract*. 2006; **72**: 315-21.
29 Pena AS, Wiltshire E, MacKenzie K, Gent R, Piotto L, Hirte C, *et al.* Vascular endothelial and smooth muscle function relates to body mass index and glucose in obese and nonobese children. *J Clin Endocrinol Metab*. 2006; **91**: 4467-71.
30 Hypponen E, Virtanen SM, Kenward MG, Knip M, Akerblom HK. Obesity, increased linear growth, and risk of type 1 diabetes in children. *Diabetes Care*. 2000; **23**: 1755-60.
31 McNamara JR, Shah PK, Nakajima K, Cupples LA, Wilson PW, Ordovas JM, *et al.* Remnant-like particle (RLP) cholesterol is an independent cardiovascular disease risk factor in women: results from the Framingham Heart Study. *Atherosclerosis*. 2001; **154**: 229-36.
32 Choi YJ, Jo YE, Kim YK, Ahn SM, Jung SH, Kim HJ, *et al.* High plasma concentration of remnant lipoprotein cholesterol in obese children and adolescents. *Diabetes Care*. 2006; **29**: 2305-10.
33 Austin MA, Breslow JL, Hennekens CH, Buring JE, Willett WC, Krauss RM. Low-density lipoprotein subclass patterns and risk of myocardial infarction. *JAMA*. 1988; **260**: 1917-21.
34 Johansson J, Carlson LA, Landou C, Hamsten A. High density lipoproteins and coronary atherosclerosis. A strong inverse relation with the largest particles is confined to normotriglyceridemic patients. *Arterioscler Thromb*. 1991; **11**: 174-82.
35 Nicklas TA, von Duvillard SP, Berenson GS. Tracking of serum lipids and lipoproteins from childhood to dyslipidemia in adults: the Bogalusa Heart Study. *Int J Sports Med*. 2002; **23 Suppl 1**: S39-43.
36 Andersen LB, Harro M, Sardinha LB, Froberg K, Ekelund U, Brage S, *et al.* Physical activity and clustered cardiovascular risk in children: a cross-sectional study (The European Youth Heart Study). *Lancet*. 2006; **368**: 299-304.
37 Ahrens W, Bammann K, de Henauw S, Halford J, Palou A, Pigeot I, *et al.* Understanding and preventing childhood obesity and related disorders--IDEFICS: a European multilevel epidemiological approach. *Nutr Metab Cardiovasc Dis*. 2006; **16**: 302-8.
38 Reilly JJ, Methven E, McDowell ZC, Hacking B, Alexander D, Stewart L, *et al.* Health consequences of obesity. *Arch Dis Child*. 2003; **88**: 748-52.
39 Castro-Rodriguez JA, Holberg CJ, Morgan WJ, Wright AL, Martinez FD. Increased incidence of asthmalike symptoms in girls who become overweight or

obese during the school years. *Am J Respir Crit Care Med*. 2001; **163**: 1344-9.

40 Visser M, Bouter LM, McQuillan GM, Wener MH, Harris TB. Low-grade systemic inflammation in overweight children. *Pediatrics*. 2001; **107**: E13.

41 Wing YK, Hui SH, Pak WM, Ho CK, Cheung A, Li AM, *et al.* A controlled study of sleep related disordered breathing in obese children. *Arch Dis Child*. 2003; **88**: 1043-7.

42 Vicente-Rodriguez G. How does exercise affect bone development during growth? *Sports Med*. 2006; **36**: 561-9.

43 Bailey DA, McKay HA, Mirwald RL, Crocker PR, Faulkner RA. A six-year longitudinal study of the relationship of physical activity to bone mineral accrual in growing children: the university of Saskatchewan bone mineral accrual study. *J Bone Miner Res*. 1999; **14**: 1672-9.

44 Erickson SJ, Robinson TN, Haydel KF, Killen JD. Are overweight children unhappy?: Body mass index, depressive symptoms, and overweight concerns in elementary school children. *Arch Pediatr Adolesc Med*. 2000; **154**: 931-5.

45 Strauss RS. Childhood obesity and self-esteem. *Pediatrics*. 2000; **105**: e15.

46 Phillips RG, Hill AJ. Fat, plain, but not friendless: self-esteem and peer acceptance of obese pre-adolescent girls. *Int J Obes Relat Metab Disord*. 1998; **22**: 287-93.

47 Wardle J, Waller J, Fox E. Age of onset and body dissatisfaction in obesity. *Addict Behav*. 2002; **27**: 561-73.

48 Vander Wal JS, Thelen MH. Eating and body image concerns among obese and average-weight children. *Addict Behav*. 2000; **25**: 775-8.

49 Brewis A. Biocultural aspects of obesity in young Mexican schoolchildren. *Am J Hum Biol*. 2003; **15**: 446-60.

50 Eisenberg ME, Neumark-Sztainer D, Story M. Associations of weight-based teasing and emotional well-being among adolescents. *Arch Pediatr Adolesc Med*. 2003; **157**: 733-8.

51 Mustillo S, Worthman C, Erkanli A, Keeler G, Angold A, Costello EJ. Obesity and psychiatric disorder: developmental trajectories. *Pediatrics*. 2003; **111**: 851-9.

52 Stice E, Bearman SK. Body-image and eating disturbances prospectively predict increases in depressive symptoms in adolescent girls: a growth curve analysis. *Dev Psychol*. 2001; **37**: 597-607.

53 Goodman E, Whitaker RC. A prospective study of the role of depression in the development and persistence of adolescent obesity. *Pediatrics*. 2002; **110**: 497-504.

54 Brown KM, McMahon RP, Biro FM, Crawford P, Schreiber GB, Similo SL, *et al.* Changes in self-esteem in black and white girls between the ages of 9 and 14 years. The NHLBI Growth and Health Study. *J Adolesc Health*. 1998; **23**: 7-19.

55 Wardle J, Cooke L. The impact of obesity on psychological well-being. *Best Pract Res Clin Endocrinol Metab*. 2005; **19**: 421-40.

56 Latner JD, Stunkard AJ. Getting worse: the stigmatization of obese children. *Obes Res*. 2003; **11**: 452-6.

57 Eisenberg ME, Neumark-Sztainer D, Haines J, Wall M. Weight-teasing and emotional well-being in adolescents: longitudinal findings from Project EAT. *J Adolesc Health*. 2006; **38**: 675-83.

58 Meers MR, Koball AM, Oehlhof MW, Laurene KR, Musher-Eizenman DR. Assessing anti-fat bias in preschoolers: a comparison of a computer generated line-drawn figure array and photographic figure array. *Body Image*. 2011; **8**: 293-6.

59 Musher-Eizenman DR, Holub SC, Miller AB, Goldstein SE, Edwards-Leeper L.

Body size stigmatization in preschool children: the role of control attributions. *J Pediatr Psychol*. 2004; **29**: 613-20.
60 Ambrosi-Randic N. Perception of current and ideal body size in preschool age children. *Percept Mot Skills*. 2000; **90**: 885-9.
61 Rand CS, Wright BA. Continuity and change in the evaluation of ideal and acceptable body sizes across a wide age span. *Int J Eat Disord*. 2000; **28**: 90-100.
62 Ricciardelli LA, McCabe MP. Children's body image concerns and eating disturbance: a review of the literature. *Clin Psychol Rev*. 2001; **21**: 325-44.
63 Davison KK, Birch LL. Processes linking weight status and self-concept among girls from ages 5 to 7 years. *Dev Psychol*. 2002; **38**: 735-48.
64 Davison KK, Markey CN, Birch LL. A longitudinal examination of patterns in girls' weight concerns and body dissatisfaction from ages 5 to 9 years. *Int J Eat Disord*. 2003; **33**: 320-32.
65 Presnell K, Bearman SK, Stice E. Risk factors for body dissatisfaction in adolescent boys and girls: a prospective study. *Int J Eat Disord*. 2004; **36**: 389-401.
66 Padgett J, Biro FM. Different shapes in different cultures: body dissatisfaction, overweight, and obesity in African-American and caucasian females. *J Pediatr Adolesc Gynecol*. 2003; **16**: 349-54.
67 Must A, Jacques PF, Dallal GE, Bajema CJ, Dietz WH. Long-term morbidity and mortality of overweight adolescents. A follow-up of the Harvard Growth Study of 1922 to 1935. *N Engl J Med*. 1992; **327**: 1350-5.
68 Sinha R, Fisch G, Teague B, Tamborlane WV, Banyas B, Allen K, *et al.* Prevalence of impaired glucose tolerance among children and adolescents with marked obesity. *N Engl J Med*. 2002; **346**: 802-10.
69 Stensel DJ, Lin FP, Ho TF, Aw TC. Serum lipids, serum insulin, plasma fibrinogen and aerobic capacity in obese and non-obese Singaporean boys. *Int J Obes Relat Metab Disord*. 2001; **25**: 984-9.
70 Jeffery RW. Public health strategies for obesity treatment and prevention. *Am J Health Behav*. 2001; **25**: 252-9.
71 French SA, Jeffery RW, Story M, Breitlow KK, Baxter JS, Hannan P, *et al.* Pricing and promotion effects on low-fat vending snack purchases: the CHIPS Study. *Am J Public Health*. 2001; **91**: 112-7.
72 Atkin LM, Davies PS. Diet composition and body composition in preschool children. *Am J Clin Nutr*. 2000; **72**: 15-21.
73 McGloin AF, Livingstone MB, Greene LC, Webb SE, Gibson JM, Jebb SA, *et al*. Energy and fat intake in obese and lean children at varying risk of obesity. *Int J Obes Relat Metab Disord*. 2002; **26**: 200-7.
74 Olds T. Obesity Wars. *Sport Health*. 2006; **24**: 6-10.
75 Gazzaniga JM, Burns TL. Relationship between diet composition and body fatness, with adjustment for resting energy expenditure and physical activity, in preadolescent children. *Am J Clin Nutr*. 1993; **58**: 21-8.
76 Eliakim A, Nemet D, Zaldivar F, McMurray RG, Culler FL, Galassetti P, *et al.* Reduced exercise-associated response of the GH-IGF-I axis and catecholamines in obese children and adolescents. *J Appl Physiol*. 2006; **100**: 1630-7.
77 Blaak EE, Saris WH. Substrate oxidation, obesity and exercise training. *Best Pract Res Clin Endocrinol Metab*. 2002; **16**: 667-78.
78 Rodriguez G, Moreno LA. Is dietary intake able to explain differences in body fatness in children and adolescents? *Nutr Metab Cardiovasc Dis*. 2006; **16**: 294-301.
79 Fisher JO, Birch LL. Restricting access to foods and children's eating. *Appetite*.

1999; **32**: 405-19.

80 Davison KK, Birch LL. Child and parent characteristics as predictors of change in girls' body mass index. *Int J Obes Relat Metab Disord*. 2001; **25**: 1834-42.

81 Birch LL, Fisher JO. Development of eating behaviors among children and adolescents. *Pediatrics*. 1998; **101**: 539-49.

82 Fisher JO, Birch LL. Parents' restrictive feeding practices are associated with young girls' negative self-evaluation of eating. *J Am Diet Assoc*. 2000; **100**: 1341-6.

83 Pate RR, Pratt M, Blair SN, Haskell WL, Macera CA, Bouchard C, *et al.* Physical activity and public health. A recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine. *JAMA*. 1995; **273**: 402-7.

84 Anderssen N, Wold B, Torsheim T. Tracking of physical activity in adolescence. *Res Q Exerc Sport*. 2005; **76**: 119-29.

85 Powell KE, Dysinger W. Childhood participation in organized school sports and physical education as precursors of adult physical activity. *Am J Prev Med*. 1987; **3**: 276-81.

86 Sallis JF, McKenzie TL. Physical education's role in public health. *Res Q Exerc Sport*. 1991; **62**: 124-37.

87 Ageing DfHa. Australia's physical activity recommendations for 5-12 year olds. Canberra, 2004.

88 McGall SE, McGuigan MR, Nottle C. Contribution of free play towards physical activity guidelines for New Zealand primary school children aged 7-9 years. *Br J Sports Med*. 2011; **45**: 120-4.

89 Tanaka C, Tanaka S. Daily physical activity in japanese preschool children evaluated by triaxial accelerometry: the relationship between period of engagement in moderate-to-vigorous physical activity and daily step counts. *J Physiol Anthropol*. 2009; **28**: 283-8.

90 Adams MA, Caparosa S, Thompson S, Norman GJ. Translating physical activity recommendations for overweight adolescents to steps per day. *Am J Prev Med*. 2009; **37**: 137-40.

91 Loucaides C, Chedzoy S. Factors influencing Cypriot children's physical activity levels. *Sport, Education and Society*. 2005; **10**: 101-18.

92 Gentle P, Caves R, Armstrong N, Balding J, Kirby B. High and low exercisers among 14- and 15-year-old children. *J Public Health Med*. 1994; **16**: 186-94.

93 Trost SG, Pate RR, Dowda M, Saunders R, Ward DS, Felton G. Gender differences in physical activity and determinants of physical activity in rural fifth grade children. *J Sch Health*. 1996; **66**: 145-50.

94 Azzarito L, Solomon M. A reconceptualization of physical education: The intersection of gender / race / social class. *Sport, Education and Society*. 2005; **10**: 25-47.

95 Ennis CD. Creating a culturally relevant curriculum for disengaged girls. *Sport, Education and Society*. 1999; **4**: 31-49.

96 O'Dea J, A. Why do kids eat healthful food? Perceived benefits of and barriers to healthful eating and physical activity among children and adolescents. *J Am Diet Assoc*. 2003; **103**: 497-501.

97 Dennison BA, Erb TA, Jenkins PL. Television viewing and television in bedroom associated with overweight risk among low-income preschool children. *Pediatrics*. 2002; **109**: 1028-35.

98 Hancox RJ, Poulton R. Watching television is associated with childhood obesity: but is it clinically important? *Int J Obes (Lond)*. 2006; **30**: 171-5.

99 Hancox RJ, Milne BJ, Poulton R. Association between child and adolescent

television viewing and adult health: a longitudinal birth cohort study. *Lancet*. 2004; **364**: 257-62.
100 Stettler N, Signer TM, Suter PM. Electronic games and environmental factors associated with childhood obesity in Switzerland. *Obes Res*. 2004; **12**: 896-903.
101 Vandewater EA, Shim MS, Caplovitz AG. Linking obesity and activity level with children's television and video game use. *J Adolesc*. 2004; **27**: 71-85.
102 Pate RR, Baranowski T, Dowda M, Trost SG. Tracking of physical activity in young children. *Med Sci Sports Exerc*. 1996; **28**: 92-6.
103 Robinson TN. Reducing children's television viewing to prevent obesity: a randomized controlled trial. *JAMA*. 1999; **282**: 1561-7.
104 Cunnane SC. Childhood origins of lifestyle-related risk factors for coronary heart disease in adulthood. *Nutr Health*. 1993; **9**: 107-15.
105 Simonen RL, Perusse L, Rankinen T, Rice T, Rao DC, Bouchard C. Familial aggregation of physical activity levels in the Quebec Family Study. *Med Sci Sports Exerc*. 2002; **34**: 1137-42.
106 Fogelholm M, Nuutinen O, Pasanen M, Myohanen E, Saatela T. Parent-child relationship of physical activity patterns and obesity. *Int J Obes Relat Metab Disord*. 1999; **23**: 1262-8.
107 Johns DP, Ha AS. Home and recess physical activity of Hong Kong children. *Res Q Exerc Sport*. 1999; **70**: 319-23.
108 Sallis JF, McKenzie TL, Elder JP, Broyles SL, Nader PR. Factors parents use in selecting play spaces for young children. *Arch Pediatr Adolesc Med*. 1997; **151**: 414-7.
109 Mathews H, Limb M, Taylor M. Reclaiming the street: the discourse of curfew. *Environment and Planning A*. 1999; **31**: 1713-30.
110 Sallis JF, Alcaraz JE, McKenzie TL, Hovell MF. Predictors of change in children's physical activity over 20 months. Variations by gender and level of adiposity. *Am J Prev Med*. 1999; **16**: 222-9.
111 Sallis JF, Prochaska JJ, Taylor WC. A review of correlates of physical activity of children and adolescents. *Med Sci Sports Exerc*. 2000; **32**: 963-75.
112 Carroll B, Loumidis J. Children’s perceived competence and enjoyment in physical education and physical activity outside school. *European Physical Education Review*. 2001; **7**: 24-43.
113 Hinckson EA, Garrett N, Duncan S. Active commuting to school in New Zealand children (2004-2008): a quantitative analysis. *Prev Med*. 2011; **52**: 332-6.
114 Yelavich S, Towns C, Burt R, Chow K, Donohue R, Sani HS, *et al.* Walking to school: frequency and predictors among primary school children in Dunedin, New Zealand. *N Z Med J*. 2008; **121**: 51-8.
115 Abley S, Chou M, Douglas M. National travel profiling part A: description of daily travel patterns. Vol. 353. NZ Transport Agency Research Report, 2008; 1-153.
116 Roberts I, Carlin J, Bennett C, Bergstrom E, Guyer B, Nolan T, *et al.* An international study of the exposure of children to traffic. *Inj Prev*. 1997; **3**: 89-93.
117 Lang D, Collins D, Kearns R. Understanding modal choice for the trip to school. *J Transp Geogr*. 2011; **19**: 509-14.
118 Collins DC, Kearns RA. The safe journeys of an enterprising school: negotiating landscapes of opportunity and risk. *Health Place*. 2001; **7**: 293-306.
119 Roberts I, Norton R, Taua B. Child pedestrian injury rates: the importance of "exposure to risk" relating to socioeconomic and ethnic differences, in Auckland, New Zealand. *J Epidemiol Community Health*. 1996; **50**: 162-5.

120 Kypri K, Chalmers DJ, Langley JD, Wright CS. Child injury mortality in New Zealand 1986-95. *J Paediatr Child Health*. 2000; **36**: 431-9.

121 Bunn F, Collier T, Frost C, Ker K, Roberts I, Wentz R. Traffic calming for the prevention of road traffic injuries: systematic review and meta-analysis. *Inj Prev*. 2003; **9**: 200-4.

122 Jones SJ, Lyons RA, John A, Palmer SR. Traffic calming policy can reduce inequalities in child pedestrian injuries: database study. *Inj Prev*. 2005; **11**: 152-6.

123 Jerrett M, McConnell R, Chang CC, Wolch J, Reynolds K, Lurmann F, *et al.* Automobile traffic around the home and attained body mass index: a longitudinal cohort study of children aged 10-18 years. *Prev Med*. 2010; **50 Suppl 1**: S50-8.

124 Tranter P, Pawson E. Children's access to local environments: A case-study of Christchurch, New Zealand. *Local Environ*. 2001; **6**: 27-48.

125 Collins DC, Kearns RA. Geographies of inequality: child pedestrian injury and walking school buses in Auckland, New Zealand. *Soc Sci Med*. 2005; **60**: 61-9.

126 Karsten L. It all used to be better? Different generations on continuity and change in urban children's daily use of space. *Children's Geographies*. 2005; **3**: 275-90.

127 Hume C, Salmon J, Ball K. Children's perceptions of their home and neighborhood environments, and their association with objectively measured physical activity: a qualitative and quantitative study. *Health Educ Res*. 2005; **20**: 1-13.

128 Valentine G, Mc Kendrick J. Children's outdoor play: Exploring parental concerns about children's safety and the changing nature of childhood. *Geoforum*. 1997; **28**: 219-35.

129 Cunningham C, Jones MA. The playground: A confession of failure? *Built Environment*. 1999; **25**: 11-17.

130 Abu-Ghazzeh TM. Children's use of the street as a playground in Abu-Nuseir, Jordan. *Environment and Behaviour*. 1998; **30**: 799-831.

131 Blatchford P, Baines E, Pellegrini A. The social context of school playground games: Sex and ethnic differences, and changes over time after entry to junior school. *British Journal of Developmental Psychology*. 2003; **21**: 481–505.

132 Alton D, Adab P, Roberts L, Barrett T. Relationship between walking levels and perceptions of the local neighbourhood environment. *Arch Dis Child*. 2007; **92**: 29-33.

133 Dollman J, Norton K, Norton L. Evidence for secular trends in children's physical activity behaviour. *Br J Sports Med*. 2005; **39**: 892-7; discussion 97.

134 Warren JM, Henry CJ, Lightowler HJ, Bradshaw SM, Perwaiz S. Evaluation of a pilot school programme aimed at the prevention of obesity in children. *Health Promot Int*. 2003; **18**: 287-96.

135 Verstraete SJ, Cardon GM, De Clercq DL, De Bourdeaudhuij IM. Increasing children's physical activity levels during recess periods in elementary schools: the effects of providing game equipment. *Eur J Pub Health*. 2006; **16**: 415-9.

136 O'Dea JA. Why do kids eat healthful food? Perceived benefits of and barriers to healthful eating and physical activity among children and adolescents. *Journal of American Diet Association*. 2003; **103**: 497-501.

137 Stratton G. A preliminary study of children's physical activity in one urban primary school playground: diVerences by sex and season. *Journal of Sport Pedagogy*. 1999; **5**: 71-81.

138 Cox M, Schofield G, Greasley N, Kolt GS. Pedometer steps in primary school-aged children: a comparison of school-based and out-of-school activity. *J Sci*

Med Sport. 2006; **9**: 91-7.
139 Duncan JS, Schofield G, Duncan EK. Pedometer-determined physical activity and body composition in New Zealand children. *Med Sci Sports Exerc*. 2006; **38**: 1402-9.
140 Duncan JS, Schofield G, Duncan EK. Step count recommendations for children based on body fat. *Prev Med*. 2007; **44**: 42-4.
141 Tudor-Locke C, Lee SM, Morgan CF, Beighle A, Pangrazi RP. Children's pedometer-determined physical activity during the segmented school day. *Med Sci Sports Exerc*. 2006; **38**: 1732-8.
142 Wickel EE, Eisenmann JC. Contribution of youth sport to total daily physical activity among 6- to 12-yr-old boys. *Med Sci Sports Exerc*. 2007; **39**: 1493-500.
143 Ding D, Sallis JF, Kerr J, Lee S, Rosenberg DE. Neighborhood environment and physical activity among youth a review. *Am J Prev Med*. 2011; **41**: 442-55.
144 Welk GJ, Corbin CB, Dale D. Measurement issues in the assessment of physical activity in children. *Res Q Exerc Sport*. 2000; **71**: S59-73.
145 Dietz WH. Critical periods in childhood for the development of obesity. *Am J Clin Nutr*. 1994; **59**: 955-9.
146 Story M. School-based approaches for preventing and treating obesity. *Int J Obes Relat Metab Disord*. 1999; **23 Suppl 2**: S43-51.
147 Dwyer JJ, Hansen B, Barrera M, Allison K, Ceolin-Celestini S, Koenig D, *et al*. Maximizing children's physical activity: an evaluability assessment to plan a community-based, multi-strategy approach in an ethno-racially and socio-economically diverse city. *Health Promot Int*. 2003; **18**: 199-208.
148 Cohen DA, Scribner RA, Farley TA. A structural model of health behavior: a pragmatic approach to explain and influence health behaviors at the population level. *Prev Med*. 2000; **30**: 146-54.
149 Sallis JF, Bauman A, Pratt M. Environmental and policy interventions to promote physical activity. *Am J Prev Med*. 1998; **15**: 379-97.
150 Marcus BH, Forsyth LH. How are we doing with physical activity? *Am J Health Promot*. 1999; **14**: 118-24.
151 Laitakari J, Vuori I, Oja P. Is long-term maintenance of health-related physical activity possible? An analysis of concepts and evidence. *Health Educ Res*. 1996; **11**: 463-77.
152 Jeffery RW, Gray CW, French SA, Hellerstedt WL, Murray D, Luepker RV, *et al*. Evaluation of weight reduction in a community intervention for cardiovascular disease risk: changes in body mass index in the Minnesota Heart Health Program. *Int J Obes Relat Metab Disord*. 1995; **19**: 30-9.
153 Jeffery RW, French SA, Raether C, Baxter JE. An environmental intervention to increase fruit and salad purchases in a cafeteria. *Prev Med*. 1994; **23**: 788-92.
154 Engwicht D (ed). *Towards an eco city: Calming the traffic*. Envirobook, Sydney, 1992.
155 Mackett RL, Lucas L, Paskins J, Turbin J. A methodology for evaluating walking school buses as an instrument of urban transport policy. *Transp Policy*. 2003; **10**: 179-86.
156 Davison KK, Werder JL, Lawson CT. Children's active commuting to school: current knowledge and future directions. *Prev Chronic Dis*. 2008; **5**: A100.
157 Johnston B, Mendoza J, Rafton S, Gonzalez-Walker D, Levinger D. Promoting physical activity and reducing child pedestrian risk: Early evaluation of a walking school bus program in central Seattle. *The Journal of Trauma Injury, Infection, and Critical Care*. 2006; **60**: 1388-89.
158 Rowland D, DiGuiseppi C, Gross M, Afolabi E, Roberts I. Randomised controlled trial of site specific advice on school travel patterns. *Arch Dis Child*.

2003; **88**: 8-11.

159 Kingham S, Ussher S. Ticket to a sustainable future: An evaluation of the long-term durability of the walking school bus programme in Christchurch, New Zealand. *Transp Policy*. 2005; **12**: 314–23.

160 Ridgers ND, Stratton G, Fairclough SJ. Assessing physical activity during recess using accelerometry. *Prev Med*. 2005; **41**: 102-7.

161 Ridgers ND, Stratton G, Fairclough SJ, Twisk JW. Long-term effects of a playground markings and physical structures on children's recess physical activity levels. *Prev Med*. 2007; **44**: 393-7.

162 Macaulay AC, Paradis G, Potvin L, Cross EJ, Saad-Haddad C, McComber A, *et al*. The Kahnawake Schools Diabetes Prevention Project: intervention, evaluation, and baseline results of a diabetes primary prevention program with a native community in Canada. *Prev Med*. 1997; **26**: 779-90.

163 Paradis G, Levesque L, Macaulay AC, Cargo M, McComber A, Kirby R, *et al*. Impact of a diabetes prevention program on body size, physical activity, and diet among Kanien'keha:ka (Mohawk) children 6 to 11 years old: 8-year results from the Kahnawake Schools Diabetes Prevention Project. *Pediatrics*. 2005; **115**: 333-9.

164 Bush PJ, Zuckerman AE, Theiss PK, Taggart VS, Horowitz C, Sheridan MJ, *et al*. Cardiovascular risk factor prevention in black schoolchildren: two-year results of the "Know Your Body" program. *Am J Epidemiol*. 1989; **129**: 466-82.

165 Tamir D, Feurstein A, Brunner S, Halfon ST, Reshef A, Palti H. Primary prevention of cardiovascular diseases in childhood: changes in serum total cholesterol, high density lipoprotein, and body mass index after 2 years of intervention in Jerusalem schoolchildren age 7-9 years. *Prev Med*. 1990; **19**: 22-30.

166 Muller MJ, Asbeck I, Mast M, Langnase K, Grund A. Prevention of obesity--more than an intention. Concept and first results of the Kiel Obesity Prevention Study (KOPS). *Int J Obes Relat Metab Disord*. 2001; **25 Suppl 1**: S66-74.

167 Robinson TN. Behavioural treatment of childhood and adolescent obesity. *Int J Obes Relat Metab Disord*. 1999; **23 Suppl 2**: S52-7.

168 Gortmaker SL, Cheung LW, Peterson KE, Chomitz G, Cradle JH, Dart H, *et al*. Impact of a school-based interdisciplinary intervention on diet and physical activity among urban primary school children: eat well and keep moving. *Arch Pediatr Adolesc Med*. 1999; **153**: 975-83.

169 Arbeit ML, Johnson CC, Mott DS, Harsha DW, Nicklas TA, Webber LS, *et al*. The Heart Smart cardiovascular school health promotion: behavior correlates of risk factor change. *Prev Med*. 1992; **21**: 18-32.

170 Brownell KD, Kaye FS. A school-based behavior modification, nutrition education, and physical activity program for obese children. *Am J Clin Nutr*. 1982; **35**: 277-83.

171 Davis SM, Going SB, Helitzer DL, Teufel NI, Snyder P, Gittelsohn J, *et al*. Pathways: a culturally appropriate obesity-prevention program for American Indian schoolchildren. *Am J Clin Nutr*. 1999; **69**: 796S-802S.

172 Caballero B, Clay T, Davis SM, Ethelbah B, Rock BH, Lohman T, *et al*. Pathways: a school-based, randomized controlled trial for the prevention of obesity in American Indian schoolchildren. *Am J Clin Nutr*. 2003; **78**: 1030-8.

173 Going S, Thompson J, Cano S, Stewart D, Stone E, Harnack L, *et al*. The effects of the Pathways Obesity Prevention Program on physical activity in American Indian children. *Prev Med*. 2003; **37**: S62-9.

174 Flores R. Dance for health: improving fitness in African American and Hispanic adolescents. *Public Health Rep*. 1995; **110**: 189-93.

175 Trevino RP, Yin Z, Hernandez A, Hale DE, Garcia OA, Mobley C. Impact of the Bienestar school-based diabetes mellitus prevention program on fasting capillary glucose levels: a randomized controlled trial. *Arch Pediatr Adolesc Med*. 2004; **158**: 911-7.
176 Manios Y, Moschandreas J, Hatzis C, Kafatos A. Evaluation of a health and nutrition education program in primary school children of Crete over a three-year period. *Prev Med*. 1999; **28**: 149-59.
177 McKenzie TL, Nader PR, Strikmiller PK, Yang M, Stone EJ, Perry CL, *et al.* School physical education: effect of the Child and Adolescent Trial for Cardiovascular Health. *Prev Med*. 1996; **25**: 423-31.
178 Sallis JF, McKenzie TL, Conway TL, Elder JP, Prochaska JJ, Brown M, *et al.* Environmental interventions for eating and physical activity: a randomized controlled trial in middle schools. *Am J Prev Med*. 2003; **24**: 209-17.
179 Simons-Morton BG, Parcel GS, Baranowski T, Forthofer R, O'Hara NM. Promoting physical activity and a healthful diet among children: results of a school-based intervention study. *Am J Public Health*. 1991; **81**: 986-91.
180 Hopper CA, Gruber MB, Munoz KD, Herb RA. Effect of including parents in a school-based exercise and nutrition program for children. *Res Q Exerc Sport*. 1992; **63**: 315-21.
181 Hopper CA, Munoz KD, Gruber MB, MacConnie S, Schonfeldt B, Shunk T. A school-based cardiovascular exercise and nutrition program with parent participation: An evaluation study. *Children's Health Care*. 1996; **25**: 221-35.
182 Hansen HS, Froberg K, Hyldebrandt N, Nielsen JR. A controlled study of eight months of physical training and reduction of blood pressure in children: the Odense schoolchild study. *BMJ*. 1991; **303**: 682-5.
183 Kain J, Uauy R, Albala, Vio F, Cerda R, Leyton B. School-based obesity prevention in Chilean primary school children: methodology and evaluation of a controlled study. *Int J Obes Relat Metab Disord*. 2004; **28**: 483-93.
184 McMurray RG, Harrell JS, Bangdiwala SI, Bradley CB, Deng S, Levine A. A school-based intervention can reduce body fat and blood pressure in young adolescents. *J Adolesc Health*. 2002; **31**: 125-32.
185 Sallis JF, McKenzie TL, Alcaraz JE, Kolody B, Faucette N, Hovell MF. The effects of a 2-year physical education program (SPARK) on physical activity and fitness in elementary school students. Sports, Play and Active Recreation for Kids. *Am J Public Health*. 1997; **87**: 1328-34.
186 Bailey RC, Olson J, Pepper SL, Porszasz J, Barstow TJ, Cooper DM. The level and tempo of children's physical activities: an observational study. *Med Sci Sports Exerc*. 1995; **27**: 1033-41.
187 Ainslie P, Reilly T, Westerterp K. Estimating human energy expenditure: a review of techniques with particular reference to doubly labelled water. *Sports Med*. 2003; **33**: 683-98.
188 MacFarlane DJ. Automated metabolic gas analysis systems: a review. *Sports Med*. 2001; **31**: 841-61.
189 Eston RG, Rowlands AV, Ingledew DK. Validity of heart rate, pedometry, and accelerometry for predicting the energy cost of children's activities. *J Appl Physiol*. 1998; **84**: 362-71.
190 Puhl J, Greaves K, Hoyt M, Baranowski T. Children's Activity Rating Scale (CARS): description and calibration. *Res Q Exerc Sport*. 1990; **61**: 26-36.
191 Sirard JR, Trost SG, Pfeiffer KA, Dowda M, Pate RR. Calibration and evaluation of an objective measure of physical activity in prechool children. *J Phys Act Health*. 2005; **2**: 345-57.
192 Crouter S, E., Schneider P, L., Karabulut M, Bassett D, R. Validity of 10

Electronic Pedometers for Measuring Steps, Distance, and Energy Cost. *Med Sci Sports Exerc*. 2003; **35**: 1455-60.

193 Lubans D, R., Morgan PJ, Tudor-Locke C. A systematic review of studies using pedometers to promote physical activity among youth. *Prev Med*. 2009; **48**: 307-15.

194 King G, A., Torres N, Potter C, Brooks T, J. , Coleman KJ. Comparison of Activity Monitors to Estimate Energy Cost of Treadmill Exercise. *Med Sci Sports Exerc*. 2004; **36**: 1244-51.

195 Hendelman D, Miller K, Baggett C, Debold E, Freedson P. Validity of accelerometry for the assessment of moderate intensity physical activity in the field. *Med Sci Sports Exerc*. 2000; **32**: S442-S49.

196 Tudor-Locke C, Craig CL, Beets MW, Belton S, Cardon GM, Duncan S, *et al.* How many steps/day are enough? for children and adolescents. *Int J Behav Nutr Phys Act*. 2011; **8**: 78.

197 Edwardson CL, Gorely T. Epoch length and its effect on physical activity intensity. *Med Sci Sports Exerc*. 2010; **42**: 928-34.

198 Van Coevering P, Harnack L, Schmitz K, Fulton JE, Galuska DA, Gao S. Feasibility of using accelerometers to measure physical activity in young adolescents. *Med Sci Sports Exerc*. 2005; **37**: 867-71.

199 Trost SG, McIver KL, Pate RR. Conducting accelerometer-based activity assessments in field-based research. *Medicine and Science in Sports Exercise*. 2005; **37**: S531-43.

200 McLeroy KR, Bibeau D, Steckler A, Glanz K. An ecological perspective on health promotion programs. *Health Educ Q*. 1988; **15**: 351-77.

201 Sallis J, F., Patrick K, Frank E, Pratt M, Wechsler H, Galuska DA. Interventions in Health Care Settings to Promote Healthful Eating and Physical Activity in Children and Adolescents. *Preventivce Medicine*. 2000; **31**: S112-S20.

202 Ajzen I. The Theory of Planned Behavior. *Organizational Behavior and Human Decisions Processes*. 1991; **50**: 179-211.

203 Bandura A. Health promotion by social cognitive means. *Health Educ Behav*. 2004; **31**: 143-64.

204 Egger G, Swinburn B. An "ecological" approach to the obesity pandemic. *BMJ*. 1997; **315**: 477-80.

205 Guinhouya BC, Lemdani M, Vilhelm C, Hubert H, Apete GK, Durocher A. How school time physical activity is the "big one" for daily activity among schoolchildren: a semi-experimental approach. *J Phys Act Health*. 2009; **6**: 510-9.

206 Badland HM, Schofield GM, Witten K, Schluter PJ, Mavoa S, Kearns RA, *et al.* Understanding the Relationship between Activity and Neighbourhoods (URBAN) Study: research design and methodology. *BMC Public Health*. 2009; **9**: 224.

207 WHO. Diet, nutrition and the prevention of chronic diseases: report of a joint WHO/FAO expert consultation. World Health Organisation, Geneva, 2003.

208 Biddle SJ, Fox KR. Motivation for physical activity and weight management. *Int J Obes Relat Metab Disord*. 1998; **22 Suppl 2**: S39-47.

209 Stone EJ, McKenzie TL, Welk GJ, Booth ML. Effects of physical activity interventions in youth. Review and synthesis. *Am J Prev Med*. 1998; **15**: 298-315.

210 West JB. *High life: a history of high-altitude physiology and medicine*. Oxford University Press, Oxford, 1998.

211 Speakman JR. The history and theory of the doubly labeled water technique. *Am J Clin Nutr*. 2001; **68**: 932S-38S.

212 Westerterp KR. Assessment of physical activity: a critical appraisal. *Eur J Appl Physiol*. 2009; **105**: 823-8.
213 Brage S, Brage N, Ekelund U, Luan J, Franks PW, Froberg K, *et al*. Effect of combined movement and heart rate monitor placement on physical activity estimates during treadmill locomotion and free-living. *Eur J Appl Physiol*. 2006; **96**: 517-24.
214 Tudor-Locke C, Williams JE, Reis JP, Pluto D. Utility of pedometers for assessing physical activity: construct validity. *Sports Med*. 2004; **34**: 281-91.
215 Maddison R, Ni Mhurchu C, Jiang Y, Vander Hoorn S, Rodgers A, Lawes CM, *et al*. International Physical Activity Questionnaire (IPAQ) and New Zealand Physical Activity Questionnaire (NZPAQ): a doubly labelled water validation. *Int J Behav Nutr Phys Act*. 2007; **4**: 62.
216 Crouter SE, Dellavalle DM, Horton M, Haas JD, Frongillo EA, Bassett DR, Jr. Validity of the Actical for estimating free-living physical activity. *Eur J Appl Physiol*. 2011; **111**: 1381-9.
217 Puyau MR, Adolph AL, Vohra FA, Zakeri I, Butte NF. Prediction of activity energy expenditure using accelerometers in children. *Med Sci Sports Exerc*. 2004; **36**: 1625-31.
218 Tudor-Locke C, Pangrazi RP, Corbin CB, Rutherford WJ, Vincent SD, Raustorp A, *et al*. BMI-referenced standards for recommended pedometer-determined steps/day in children. *Prev Med*. 2004; **38**: 857-64.
219 Sterne JA, Davey Smith G. Sifting the evidence-what's wrong with significance tests? *BMJ*. 2001; **322**: 226-31.
220 Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc*. 2009; **41**: 3-13.
221 McLean RA, Sanders WL, Stroup WW. A unified approach to mixed linear models. *The American Statistician* 1991; **45**: 54-64.
222 Bland MJ, Altman DG. The odds ratio. *Br Med J*. 2000; **320** 1468.
223 Bennette C, Andrew V. Against quantiles: categorization of continuous variables in epidemiologic research, and its discontents. *BMC Medical Research Methodology*. 2012; **12**: 1-5.
224 Altman D, C., Bland M, J. Quartiles, quintiles, centiles, and other quantiles. *British Medical Journal (Statistics Notes)*. 1994; **309**: 996.
225 DiCiccio TJ, Efron B. Bootstrap Confidence Intervals. *Statistical Science*. 1996; **11**: 189-228.
226 Pikora T, Giles-Corti B, Bull F, Jamrozik K, Donovan R. Developing a framework for assessment of the environmental determinants of walking and cycling. *Soc Sci Med*. 2003; **56**: 1693-703.
227 Fenton M. Community design and policies for free-range children: creating environments that support routine physical activity. *Child Obes*. 2012; **8**: 44-51.
228 Rainham D, Krewski D, McDowell I, Sawada M, Liekens B. Development of a wearable global positioning system for place and health research. *Int J Health Geogr*. 2008; **7**: 59.
229 Leslie E, Coffee N, Frank L, Owen N, Bauman A, Hugo G. Walkability of local communities: using geographic information systems to objectively assess relevant environmental attributes. *Health Place*. 2007; **13**: 111-22.
230 D'Souza E, Forsyth A, Koepp J, Oakes J, Schmitz K, Zimmerman J. Twin Cities walking study. Environment and physical activity: GIS protocols, Version 3.1 Metropolitan Design Center, University of Minnesota, Minneapolis, 2006.
231 Wong BY, Faulkner G, Buliung R. GIS measured environmental correlates of active school transport: a systematic review of 14 studies. *Int J Behav Nutr Phys*

Act. 2011; **8**: 39.

232 Boarnet MG, Day K, Alfonzo M, Forsyth A, Oakes M. The Irvine-Minnesota inventory to measure built environments: reliability tests. *Am J Prev Med*. 2006; **30**: 153-59.

233 Lachowycz K, Jones AP, Page AS, Wheeler BW, Cooper AR. What can global positioning systems tell us about the contribution of different types of urban greenspace to children's physical activity? *Health Place*. 2012; **18**: 586-94.

234 Rainham D, McDowell I, Krewski D, Sawada M. Conceptualizing the healthscape: contributions of time geography, location technologies and spatial ecology to place and health research. *Soc Sci Med*. 2010; **70**: 668-76.

235 Krenn PJ, Titze S, Oja P, Jones A, Ogilvie D. Use of global positioning systems to study physical activity and the environment: a systematic review. *Am J Prev Med*. 2011; **41**: 508-15.

236 Tudor-Locke C, Johnson WD, Katzmarzyk PT. Accelerometer-determined steps per day in US children and youth. *Med Sci Sports Exerc*. 2010; **42**: 2244-50.

237 Craig CL, Cameron C, Griffiths JM, Tudor-Locke C. Descriptive epidemiology of youth pedometer-determined physical activity: CANPLAY. *Med Sci Sports Exerc*. 2010; **42**: 1639-43.

238 Cooper AR, Page AS, Wheeler BW, Griew P, Davis L, Hillsdon M, *et al.* Mapping the walk to school using accelerometry combined with a global positioning system. *Am J Prev Med*. 2010; **38**: 178-83.

239 McDonald K, Hearst M, Farbakhsh K, Patnode C, Forsyth A, Sirard J, *et al.* Adolescent physical activity and the built environment: a latent class analysis approach. *Health Place*. 2012; **18**: 191-8.

240 Rodriguez DA, Cho GH, Evenson KR, Conway TL, Cohen D, Ghosh-Dastidar B, *et al.* Out and about: association of the built environment with physical activity behaviors of adolescent females. *Health Place*. 2012; **18**: 55-62.

241 Cooper AR, Page AS, Wheeler BW, Hillsdon M, Griew P, Jago R. Patterns of GPS measured time outdoors after school and objective physical activity in English children: the PEACH project. *Int J Behav Nutr Phys Act*. 2010; **7**: 31.

242 Quigg R, Gray A, Reeder AI, Holt A, Waters DL. Using accelerometers and GPS units to identify the proportion of daily physical activity located in parks with playgrounds in New Zealand children. *Prev Med*. 2010; **50**: 235-40.

243 Roemmich JN, Epstein LH, Raja S, Yin L, Robinson J, Winiewicz D. Association of access to parks and recreational facilities with the physical activity of young children. *Prev Med*. 2006; **43**: 437-41.

244 Carver A, Timperio A, Hesketh K, Crawford D. Are safety-related features of the road environment associated with smaller declines in physical activity among youth? *J Urban Health*. 2010; **87**: 29-43.

245 Crawford D, Cleland V, Timperio A, Salmon J, Andrianopoulos N, Roberts R, *et al*. The longitudinal influence of home and neighbourhood environments on children's body mass index and physical activity over 5 years: the CLAN study. *Int J Obes (Lond)*. 2010; **34**: 1177-87.

246 Scott MM, Evenson KR, Cohen DA, Cox CE. Comparing perceived and objectively measured access to recreational facilities as predictors of physical activity in adolescent girls. *J Urban Health*. 2007; **84**: 346-59.

247 Almanza E, Jerrett M, Dunton G, Seto E, Pentz MA. A study of community design, greenness, and physical activity in children using satellite, GPS and accelerometer data. *Health Place*. 2012; **18**: 46-54.

248 Dunton GF, Liao Y, Almanza E, Jerrett M, Spruijt-Metz D, Chou CP, *et al.* Joint physical activity and sedentary behavior in parent-child pairs. *Med Sci Sports Exerc*. 2012; **44**: 1473-80.

249 Jones AP, Coombes EG, Griffin SJ, van Sluijs EM. Environmental supportiveness for physical activity in English schoolchildren: a study using Global Positioning Systems. *Int J Behav Nutr Phys Act*. 2009; **6**: 42.

250 Rainham DG, Bates CJ, Blanchard CM, Dummer TJ, Kirk SF, Shearer CL. Spatial classification of youth physical activity patterns. *Am J Prev Med*. 2012; **42**: e87-96.

251 Dowda M, McKenzie TL, Cohen DA, Scott MM, Evenson KR, Bedimo-Rung AL, *et al*. Commercial venues as supports for physical activity in adolescent girls. *Prev Med*. 2007; **45**: 163-8.

252 Scott MM, Cohen DA, Evenson KR, Elder J, Catellier D, Ashwood JS, *et al*. Weekend schoolyard accessibility, physical activity, and obesity: the Trial of Activity in Adolescent Girls (TAAG) study. *Prev Med*. 2007; **44**: 398-403.

253 Jago R, Baranowski T, Zakeri I, Harris M. Observed environmental features and the physical activity of adolescent males. *Am J Prev Med*. 2005; **29**: 98-104.

254 Jago R, Baranowski T, Baranowski JC. Observed, GIS, and self-reported environmental features and adolescent physical activity. *Am J Health Promot*. 2006; **20**: 422-8.

255 Aytur SA, Rodriguez DA, Evenson KR, Catellier DJ, Rosamond WD. The sociodemographics of land use planning: relationships to physical activity, accessibility, and equity. *Health Place*. 2008; **14**: 367-85.

256 Neckerman KM, Lovasi GS, Davies S, Purciel M, Quinn J, Feder E, *et al*. Disparities in urban neighborhood conditions: evidence from GIS measures and field observation in New York City. *J Public Health Policy*. 2009; **30 Suppl 1**: S264-85.

257 Carver A, Timperio AF, Crawford DA. Neighborhood road environments and physical activity among youth: the CLAN study. *J Urban Health*. 2008; **85**: 532-44.

258 Timperio A, Giles-Corti B, Crawford D, Andrianopoulos N, Ball K, Salmon J, *et al*. Features of public open spaces and physical activity among children: findings from the CLAN study. *Prev Med*. 2008; **47**: 514-8.

259 Patnode CD, Lytle LA, Erickson DJ, Sirard JR, Barr-Anderson D, Story M. The relative influence of demographic, individual, social, and environmental factors on physical activity among boys and girls. *Int J Behav Nutr Phys Act*. 2010; **7**: 79.

260 Maddison R, Jiang Y, Vander Hoorn S, Ni Mhurchu C, Exeter D, Utter J. Perceived versus actual distance to local physical-activity facilities: does it really matter? *J Phys Act Health*. 2010; **7**: 323-32.

261 Prins RG, Ball K, Timperio A, Salmon J, Oenema A, Brug J, *et al*. Associations between availability of facilities within three different neighbourhood buffer sizes and objectively assessed physical activity in adolescents. *Health Place*. 2011; **17**: 1228-34.

262 Ries AV, Voorhees CC, Roche KM, Gittelsohn J, Yan AF, Astone NM. A quantitative examination of park characteristics related to park use and physical activity among urban youth. *J Adolesc Health*. 2009; **45**: S64-70.

263 Roemmich JN, Epstein LH, Raja S, Yin L. The neighborhood and home environments: disparate relationships with physical activity and sedentary behaviors in youth. *nn Behav Med*. 2007; **33**: 29-38.

264 Stevens RB, Brown BB. Walkable new urban LEED_Neighborhood-Development (LEED-ND) community design and children's physical activity: selection, environmental, or catalyst effects? *Int J Behav Nutr Phys Act*. 2011; **8**: 139.

265 Van Dyck D, Cardon G, Deforche B, De Bourdeaudhuij I. Lower neighbourhood

walkability and longer distance to school are related to physical activity in Belgian adolescents. *Prev Med*. 2009; **48**: 516-8.

266 Oreskovic NM, Blossom J, Field AE, Chiang SR, Winickoff JP, Kleinman RE. Combining global positioning system and accelerometer data to determine the locations of physical activity in children. *Geospat Health*. 2012; **6**: 263-72.

267 Southward EF, Page AS, Wheeler BW, Cooper AR. Contribution of the school journey to daily physical activity in children aged 11-12 years. *Am J Prev Med*. 2012; **43**: 201-4.

268 Wheeler BW, Cooper AR, Page AS, Jago R. Greenspace and children's physical activity: a GPS/GIS analysis of the PEACH project. *Prev Med*. 2010; **51**: 148-52.

269 Treuth MS, Schmitz K, Catellier DJ, McMurray RG, Murray DM, Almeida MJ, *et al*. Defining accelerometer thresholds for activity intensities in adolescent girls. *Med Sci Sports Exerc*. 2004; **36**: 1259-66.

270 Puyau MR, Adolph AL, Vohra FA, Butte NF. Validation and calibration of physical activity monitors in children. *Obes Res*. 2002; **10**: 150-7.

271 Brage S, Wedderkopp N, Franks PW, Andersen LB, Froberg K. Reexamination of validity and reliability of the CSA monitor in walking and running. *Med Sci Sports Exerc*. 2003; **35**: 1447-54.

272 Evenson KR, Catellier DJ, Gill K, Ondrak KS, McMurray RG. Calibration of two objective measures of physical activity for children. *J Sports Sci*. 2008; **26**: 1557-65.

273 Freedson PS, Melanson E, Sirard J. Calibration of the Computer Science and Applications, Inc. accelerometer. *Med Sci Sports Exerc*. 1998; **30**: 777-81.

274 Voorhees CC, Catellier DJ, Ashwood JS, Cohen DA, Rung A, Lytle L, *et al*. Neighborhood socioeconomic status and non school physical activity and body mass index in adolescent girls. *J Phys Act Health*. 2009; **6**: 731-40.

275 Giles-Corti B, Timperio A, Bull F, Pikora T. Understanding physical activity environmental correlates: increased specificity for ecological models. *Exerc Sport Sci Rev*. 2005; **33**: 175-81.

276 Posner JC, Liao E, Winston FK, Cnaan A, Shaw KN, Durbin DR. Exposure to traffic among urban children injured as pedestrians. *Inj Prev*. 2002; **8**: 231-5.

277 Shepherd M, Austin P, Chambers J. Driveway runover, the influence of the built environment: a case control study. *J Paediatr Child Health*. 2010; **46**: 760-7.

278 Gielen AC, Defrancesco S, Bishai D, Mahoney P, Ho S, Guyer B. Child pedestrians: the role of parental beliefs and practices in promoting safe walking in urban neighborhoods. *J Urban Health*. 2004; **81**: 545-55.

279 Carver A, Timperio A, Hesketh K, Crawford D. Are children and adolescents less active if parents restrict their physical activity and active transport due to perceived risk? *Soc Sci Med*. 2010; **70**: 1799-805.

280 Brockman R, Jago R, Fox KR. The contribution of active play to the physical activity of primary school children. *Prev Med*. 2010; **51**: 144-7.

281 Corder K, Sallis JF, Crespo NC, Elder JP. Active children use more locations for physical activity. *Health Place*. 2011; **17**: 911-9.

282 Mavoa S, Witten K, Pearce J, Day P. Measuring neighbourhood walkability in New Zealand cities. Massey University, Auckland, 2009; 1-29.

283 Witten K, Pearce J, Day P. Neighbourhood Destination Accessibility Index: a GIS tool for measuring infrastructure support for neighbourhood physical activity. *Environment and Planning A*. 2011; **43**: 205-23.

284 Janz KF, Rao S, Baumann HJ, Schultz JL. Measuring children's vertical ground reaction forces with accelerometry during walking, running, and jumping: The Iowa Bone Development Study. *Pediatr Exerc Sci*. 2003; **15**: 34-43.

285 Pfeiffer KA, McIver KL, Dowda M, Almeida MJ, Pate RR. Validation and calibration of the Actical accelerometer in preschool children. *Med Sci Sports Exerc*. 2006; **38**: 152-7.

286 Colley RC, Tremblay MS. Moderate and vigorous physical activity intensity cut-points for the Actical accelerometer. *J Sports Sci*. 2011; **29**: 783-9.

287 Colley R, Gorber SC, Tremblay MS. Quality control and data reduction procedures for accelerometry-derived measures of physical activity. *Health Rep*. 2010; **21**: 63-9.

288 Statistics NZ. Census of population and dwellings: Auckland City. What we look like locally. Statistics New Zealand, Wellington, 2006; 1-21.

289 Rodriguez DA, Aytur S, Forsyth A, Oakes JM, Clifton KJ. Relation of modifiable neighborhood attributes to walking. *Prev Med*. 2008; **47**: 260-4.

290 Petch RO, Henson RR. Child road safety in the urban environment. *J Transp Geogr*. 2000; **8**: 197-211.

291 Tester JM, Rutherford GW, Wald Z, Rutherford MW. A matched case-control study evaluating the effectiveness of speed humps in reducing child pedestrian injuries. *Am J Public Health*. 2004; **94**: 646-50.

292 Villanueva K, Giles-Corti B, Bulsara M, McCormack GR, Timperio A, Middleton N, *et al*. How far do children travel from their homes? Exploring children's activity spaces in their neighborhood. *Health Place*. 2012; **18**: 263-73.

293 Purcell C, Wann JP, Wilmut K, Poulter D. Reduced looming sensitivity in primary school children with Developmental Co-ordination Disorder. *Dev Sci*. 2012; **15**: 299-306.

294 MOT. Yearly Report 2011 Motor vehicle crashes in New Zealand 2010 Statistical Statement. Research Statistics Ministry of Transport, 2011; 1-181.

295 Rifaat SM, Tay R, de Barros A. Urban Street Pattern and Pedestrian Traffic Safety. *Journal of Urban Design*. 2012; **17**: 337-52.

296 Karkee GJ, Nambisan SS, Pulugurtha SS. Motorist actions at a crosswalk with an in-pavement flashing light system. *Traffic Inj Prev*. 2010; **11**: 642-9.

297 Mackie H. Improving school travel systems. Vol. 420. NZ Transport Agency Research Report, 2010; 1-86.

298 Dunton GF, Intille SS, Wolch J, Pentz MA. Investigating the impact of a smart growth community on the contexts of children's physical activity using Ecological Momentary Assessment. *Health Place*. 2012; **18**: 76-84.

299 Tudor-Locke C, Craig CL, Cameron C, Griffiths JM. Canadian children's and youth's pedometer-determined steps/day, parent-reported TV watching time, and overweight/obesity: the CANPLAY Surveillance Study. *Int J Behav Nutr Phys Act*. 2011; **8**: 66.

300 Riddoch CJ, Mattocks C, Deere K, Saunders J, Kirkby J, Tilling K, *et al*. Objective measurement of levels and patterns of physical activity. *Arch Dis Child*. 2007; **92**: 963-9.

301 Duncan JS, Hopkins WG, Schofield G, Duncan EK. Effects of weather on pedometer-determined physical activity in children. *Med Sci Sports Exerc*. 2008; **40**: 1432-8.

302 Clinical Trials Research Unit S. A National Survey of Children and Young People's Physical Activity and Dietary Behaviours in New Zealand: 2008/09 - Key Findings. Ministry of Health, Wellington, 2010.

303 Ramirez-Marrero FA, Smith BA, Sherman WM, Kirby TE. Comparison of methods to estimate physical activity and energy expenditure in African American children. *Int J Sports Med*. 2005; **26**: 363-71.

304 Esliger DW, Probert A, Gorber SC, Bryan S, Laviolette M, Tremblay MS. Validity of the Actical accelerometer step-count function. *Med Sci Sports Exerc*.

2007; **39**: 1200-4.

305 Tremblay MS, Warburton DE, Janssen I, Paterson DH, Latimer AE, Rhodes RE, *et al*. New Canadian physical activity guidelines. *Appl Physiol Nutr Metab*. 2011; **36**: 36-46; 47-58.

306 Bassett DR, Jr., Rowlands A, Trost SG. Calibration and validation of wearable monitors. *Med Sci Sports Exerc*. 2012; **44**: S32-8.

307 Matthews CE, Hagstromer M, Pober DM, Bowles HR. Best practices for using physical activity monitors in population-based research. *Med Sci Sports Exerc*. 2012; **44**: S68-76.

308 Welk GJ, McClain J, Ainsworth BE. Protocols for evaluating equivalency of accelerometry-based activity monitors. *Med Sci Sports Exerc*. 2012; **44**: S39-49.

309 Trost SG, Pate RR, Sallis JF, Freedson PS, Taylor WC, Dowda M, *et al*. Age and gender differences in objectively measured physical activity in youth. *Med Sci Sports Exerc*. 2002; **34**: 350-5.

310 Caprio S, Daniels SR, Drewnowski A, Kaufman FR, Palinkas LA, Rosenbloom AL, *et al*. Influence of race, ethnicity, and culture on childhood obesity: implications for prevention and treatment. *Obesity (Silver Spring)*. 2008; **16**: 2566-77.

311 Beets MW, Le Masurier GC, Beighle A, Rowe DA, Morgan CF, Rutherford J, *et al*. Are current body mass index referenced pedometer step-count recommendations applicable to US youth? *J Phys Act Health*. 2008; **5**: 665-74.

312 Eisenmann JC, Laurson KR, Wickel EE, Gentile D, Walsh D. Utility of pedometer step recommendations for predicting overweight in children. *Int J Obes (Lond)*. 2007; **31**: 1179-82.

313 Valentine GJ, McKendrick J. Children’s Outdoor Play: Exploring Parental Concerns About Children’s Safety and the Changing Nature of Childhood. *Geoforum*. 1997; **28**: 219-35.

314 Reilly JJ, Penpraze V, Hislop J, Davies G, Grant S, Paton JY. Objective measurement of physical activity and sedentary behaviour: review with new data. *Arch Dis Child*. 2008; **93**: 614-9.

315 Sirard JR, Slater ME. Compliance with wearing physical activity accelerometers in high school students. *J Phys Act Health*. 2009; **6 Suppl 1**: S148-55.

316 Guinhouya CB, Apete GK, Hubert H. Diagnostic quality of Actigraph-based physical activity cut-offs for children: what overweight/obesity references can tell? *Pediatr Int*. 2009; **51**: 568-73.

317 Leenders NY, Sherman WM, Nagaraja HN. Energy expenditure estimated by accelerometry and doubly labeled water: do they agree? *Med Sci Sports Exerc*. 2006; **38**: 2165-72.

318 Webber LS, Catellier DJ, Lytle LA, Murray DM, Pratt CA, Young DR, *et al*. Promoting physical activity in middle school girls: Trial of Activity for Adolescent Girls. *Am J Prev Med*. 2008; **34**: 173-84.

319 NZME. The New Zealand Curriculum. New Zealand Ministry of Education, Wellington, 2007; 22-24.

320 Esliger DW, Tremblay MS. Technical reliability assessment of three accelerometer models in a mechanical setup. *Med Sci Sports Exerc*. 2006; **38**: 2173-81.

321 Nader PR, Bradley RH, Houts RM, McRitchie SL, O'Brien M. Moderate-to-vigorous physical activity from ages 9 to 15 years. *JAMA*. 2008; **300**: 295-305.

322 Masse LC, Fuemmeler BF, Anderson CB, Matthews CE, Trost SG, Catellier DJ, *et al*. Accelerometer data reduction: a comparison of four reduction algorithms on select outcome variables. *Med Sci Sports Exerc*. 2005; **37**: S544-54.

323 Harris KC, Kuramoto LK, Schulzer M, Retallack JE. Effect of school-based

physical activity interventions on body mass index in children: a meta-analysis. *Can Med Assoc J*. 2009; **180**: 719-26.

324 Nemet D, Barkan S, Epstein Y, Friedland O, Kowen G, Eliakim A. Short- and long-term beneficial effects of a combined dietary-behavioral-physical activity intervention for the treatment of childhood obesity. *Pediatrics*. 2005; **115**: e443-9.

325 Lohman T, Thompson J, Going S, Himes JH, Caballero B, Norman J, *et al*. Indices of changes in adiposity in American Indian children. *Prev Med*. 2003; **37**: S91-6.

326 Treuth MS, Sherwood NE, Butte NF, McClanahan B, Obarzanek E, Zhou A, *et al*. Validity and reliability of activity measures in African-American girls for GEMS. *Med Sci Sports Exerc*. 2003; **35**: 532-9.

327 Hopkins WG. Measures of reliability in sports medicine and science. *Sports Med*. 2000; **30**: 1-15.

328 Berman N, Bailey R, Barstow TJ, Cooper DM. Spectral and bout detection analysis of physical activity patterns in healthy, prepubertal boys and girls. *Am J Hum Biol*. 1998; **10**: 289-97.

329 Baquet G, Stratton G, Van Praagh E, Berthoin S. Improving physical activity assessment in prepubertal children with high-frequency accelerometry monitoring: a methodological issue. *Prev Med*. 2007; **44**: 143-7.

330 Nader PR, Bradley RH, Houts RM, McRitchie SL, O'Brien M. Moderate-to-vigorous physical activity from ages 9 to 15 years. *J Am Med Assoc*. 2008; **300**: 295-305.

331 Becker BJ. Synthesizing standardized mean-change measures. *Br J Math Stat Psychol*. 1988; **41**: 257-78.

332 Tee TY, Ng HS, Lim CT, Pek E, Zhong Z. Impact life prediction modeling of TFBGA packages under board level drop test. *Microelectronics and Reliability*. 2004; **44**: 1113-42.

333 Moeller NC, Korsholm L, Kristensen PL, Andersen LB, Wedderkopp N, Froberg K. Unit-specific calibration of Actigraph accelerometers in a mechanical setup - is it worth the effort? The effect on random output variation caused by technical inter-instrument variability in the laboratory and in the field. *BMC Medical Research Methodology*. 2008; **8**: 19.

334 Heil DP. Predicting activity energy expenditure using the Actical activity monitor. *Res Q Exerc Sport*. 2006; **77**: 64-80.

335 Hausswirth C, Le Meur Y, Couturier A, Bernard T, Brisswalter J. Accuracy and repeatability of the Polar RS800sd to evaluate stride rate and running speed. *Int J Sports Med*. 2009; **30**: 354-9.

336 Janz KF, Letuchy EM, Eichenberger Gilmore JM, Burns TL, Torner JC, Willing MC, *et al*. Early physical activity provides sustained bone health benefits later in childhood. *Med Sci Sports Exerc*. 2010; **42**: 1072-8.

337 Brage S, Wedderkopp N, Ekelund U, Franks PW, Wareham NJ, Andersen LB, *et al*. Objectively measured physical activity correlates with indices of insulin resistance in Danish children. The European Youth Heart Study (EYHS). *Int J Obes Relat Metab Disord*. 2004; **28**: 1503-8.

338 Ridgers ND, Toth M, Uvacsek M. Physical activity levels of Hungarian children during school recess. *Prev Med*. 2009; **49**: 410-2.

339 Freedson P, Pober D, Janz KF. Calibration of accelerometer output for children. *Med Sci Sports Exerc*. 2005; **37**: S523-30.

340 Nilsson A, Ekelund U, Yngve A, Sjostrom M. Assessing physical activity among children with accelerometers using different time sampling intervals and placements. *Pediatr Exerc Sci*. 2002; **14**: 87-96.

341 McClain JJ, Abraham TL, Brusseau TA, Jr., Tudor-Locke C. Epoch length and accelerometer outputs in children: comparison to direct observation. *Med Sci Sports Exerc*. 2008; **40**: 2080-7.
342 Crouter SE, Churilla JR, Bassett DR, Jr. Estimating energy expenditure using accelerometers. *Eur J Appl Physiol*. 2006; **98**: 601-12.
343 Duncan MJ, Al-Nakeeb Y, Woodfield L, Lyons M. Pedometer determined physical activity levels in primary school children from central England. *Prev Med*. 2007; **44**: 416-20.
344 Cooper AR, Andersen LB, Wedderkopp N, Page AS, Froberg K. Physical activity levels of children who walk, cycle, or are driven to school. *Am J Prev Med*. 2005; **29**: 179-84.
345 Rowlands AV, Pilgrim EL, Eston RG. Patterns of habitual activity across weekdays and weekend days in 9-11-year-old children. *Prev Med*. 2008; **46**: 317-24.
346 Wilkin TJ, Mallam KM, Metcalf BS, Jeffery AN, Voss LD. Variation in physical activity lies with the child, not his environment: evidence for an 'activitystat' in young children (EarlyBird 16). *Int J Obes*. 2006; **30**: 1050-5.
347 Schutz Y, Weinsier RL, Hunter GR. Assessment of free-living physical activity in humans: an overview of currently available and proposed new measures. *Obes Res*. 2001; **9**: 368-79.
348 Kesaniemi YK, Danforth E, Jr., Jensen MD, Kopelman PG, Lefebvre P, Reeder BA. Dose-response issues concerning physical activity and health: an evidence-based symposium. *Med Sci Sports Exerc*. 2001; **33**: S351-8.
349 Rowland TW, Auchinachie JA, Keenan TJ, Green GM. Submaximal aerobic running economy and treadmill performance in prepubertal boys. *Int J Sports Med*. 1988; **9**: 201-4.
350 Wann JP, Poulter DR, Purcell C. Reduced Sensitivity to Visual Looming Inflates the Risk Posed by Speeding Vehicles When Children Try to Cross the Road. *Psychol Sci*. 2011; **22**: 429-34.
351 Kingham S, Sabel CE, Bartie P. The impact of the ‘school run’ on road traffic accidents: A spatio-temporal analysis. *J Transp Geogr*. 2011; **19**: 705-11.
352 Transalt.org. Rethinking bollards: How bollards can save lives, prevent injuries and relieve traffic congestion in New York City Transportation-Alternatives, 2007; 1-25.
353 Rowlands AV, Stiles VH. Accelerometer counts and raw acceleration output in relation to mechanical loading. *J Biomech*. 2012; **45**: 448-54.
354 Phillips LR, Parfitt G, Rowlands AV. Calibration of the GENEA accelerometer for assessment of physical activity intensity in children. *J Sci Med Sport*. 2013; **16**: 124-8.

APPENDICES

APPENDIX A: PARTICIPANT INFORMATION SHEET FOR THE URBAN STUDY: A NATIONAL AND INTERNATIONAL PROJECT (STUDY 1-2; CHAPTERS 3-4)

Participant Information Sheet

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

THE UNIVERSITY OF AUCKLAND
NEW ZEALAND
Te Whare Wānanga o Tāmaki Makaurau

UNIVERSITY of OTAGO
Te Whare Wānanga o Otāgo

Massey University

Date Information Sheet Produced: 15th July 2007

Project Title
The URBAN study: A national and international project

An Invitation
You are invited to take part in this study which is about how your local neighbourhood environment may affect your physical activity levels and body size. This is part of a national (North Shore, Waitakere, Wellington, and Christchurch cities) and eight-country international study. Information is being collected in your neighbourhood by *[insert research assistant's name here]* (research assistant), and the study is being undertaken by Auckland University of Technology, Massey University, the University of Auckland, and Wellington School of Medicine, University of Otago. The Health Research Council of New Zealand has funded the research. Your participation is strictly voluntary, and if you choose to participate, you are free to withdraw from the research at any time without giving reason and with no adverse consequences.

What is the purpose of this research?
This project seeks to explore the associations between physical activity levels and body size in adults and children with neighbourhood variables. Objective and self-report measures of you and your child's (if applicable) physical activity levels, body size, and neighbourhood will be taken by a research assistant. The research assistant will also ask a few related questions about you and your child (if applicable). The outcomes of this research will directly inform national urban design and town planning policies, in the hope of sustainably increasing physical activity engagement and reducing obesity within your community. Information will be passed on to yourself, stakeholders, councils, and academic audiences.

How was I chosen for this invitation?
Forty eight neighbourhoods in North Shore, Waitakere, Wellington, and Christchurch cities have been selected for this study, and your household was randomly selected from these neighbourhoods.

The adult and child (should the household contain a child) who usually lives in this household with the next birthdays are invited to participate in this study. Adults have to be 20-65 years of age and children 3-12 years of age to participate in the study. People will be unable to participate in the study if have severe walking mobility restrictions, or are not fluent in English.

What will happen in this research?
The research assistant will meet with you on at least two occasions. At the first meeting (Interview 1) the research assistant will introduce the study, and if possible gain permission for an adult and child to participate in the study, and explain and distribute the accelerometers and compliance logs. The adult and child (if applicable) are required to wear an accelerometer around their waist for seven-days from Interview 1. A picture of an accelerometer is shown below.

The accelerometer is worn on a band around your waist and it is slightly smaller than a matchbox. The accelerometer can be removed for sleeping, bathing, and water sports. An accelerometer compliance log should also be completed at the end of each day for the seven days. At the second meeting (Interview 2) (eight days after the first meeting) the research assistant will return to your home at a pre-arranged time and collect the accelerometer(s) and compliance log(s), complete the questionnaires with you, and take height, weight, and waist circumference measures. The results will be entered directly onto a small hand-held computer (personal digital assistant, PDA).

What are the discomforts and risks?
No clinical or psychological discomforts or risks are anticipated from participating in the study.

What are the benefits?
This study provides you with an opportunity to have input into research that has the potential to inform the development of local and national policy initiatives on physical activity and obesity, and the planning of the local communities, such as neighbourhoods. You will also get personalised feedback about your physical activity levels, body size, and neighbourhood environment.

How will my privacy be protected?
The information collected from you will be kept strictly confidential, and will be stored as coded (instead of named) information. The consent forms will be kept separate from other information collected and will be locked away and kept strictly confidential. Information will be destroyed after 6 years. Apart from your personalised feedback, no participants will be identified in any research reports.

What are the costs of participating in this research?
It is estimated that Interview 1 will take approximately 20 minutes and Interview 2 will take 40 minutes to complete. It will take approximately 1 minute each day to put on and remove the accelerometer and complete the compliance log during the seven-day accelerometer wearing period. To thank participants for their time commitment and effort, all respondents who complete data collection will be entered into a draw to win a weekend's accommodation and a return airfare for two to Sydney.

What opportunity do I have to consider this invitation?
A research assistant will be in your neighbourhood during the next couple of weeks. Over the next few days, the research assistant will stop by your home to enquire if you would like to participate in the study.

How do I agree to participate in this research?
If you agree to participate in the research, you will need to complete a consent form. The research assistant will have one of these for you, and will stop by your home over the next few days to enquire if you would like to participate in this study.

Will I receive feedback on the results of this research?
As part of the study you will receive a copy of your personal physical activity, body size, and neighbourhood findings based on your objective measures and comments. This information will be posted to you after your information has been analysed. A research summary will be made available to you on request at the completion of the study. Anonymous summary results of this research will be reported back to community groups and stakeholders, and will also be published in peer-reviewed academic journals and as part of two PhD theses.

What do I do if I have concerns about this research?
Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr Hannah Badland, *hannah.badland@aut.ac.nz*, (09) 921 9999 ext 7630.

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, *madeline.banda@aut.ac.nz*, (09) 921 9999 ext 8044.

Whom do I contact for further information about this research?

Researcher contact details:

Research assistant *[to be inserted when appointed]*
Phone:
Email:

PROJECT SUPERVISOR CONTACT DETAILS:

Dr Hannah Badland (Project Supervisor, Auckland University of Technology)
Phone: (09) 921 9999 ext 7630
Email: hannah.badland@aut.ac.nz

Professor Grant Schofield (Co-Leader, Auckland University of Technology)
Phone: (09) 921 9999 ext 7307
Email: grant.schofield@aut.ac.nz

Approved by the Auckland University of Technology Ethics Committee on *21 September 2007*, AUTEC Reference number *07/126*.

APPENDIX B: CHILD PARTICIPANT INFORMATION SHEET FOR THE URBAN STUDY: A NATIONAL AND INTERNATIONAL PROJECT (STUDY 1-2; CHAPTERS 3-4)

Participant Information Sheet

THE URBAN STUDY: A NATIONAL AND INTERNATIONAL STUDY

INFORMATION SHEET AND ASSENT FORM FOR CHILDREN

(parent/caregivers please read to children)

This form will be kept for a period of 6 years

Hello – my name is *[insert name here when research officer is appointed]*.

I would like to spend time some time at your home. I will come to your house twice over the next week.

When I am there I will do some talking and writing and you will notice me. You can talk to me and we can get to know each other. You can ask me about my work whenever you want to. Let me know how you feel about this by colouring in or circling one of these words:

Happy Fine

Not Sure

Worried

If you are not sure or worried come and talk to me about it or ask one of your parents/caregivers about this.

I am finding out about what you and your parents/caregivers do in your neighbourhood, where you play, how you travel places, and the size of your body – you might like to find out about this as well.

I am asking one of your parents/caregivers about you, and asking you to wear a small box on a band around your waist called an accelerometer for a week. This will measure some of the things you do. We will all work together on this.

Here is a picture of an accelerometer:

Thank you for completing this form – will you ask your parent/caregiver to sign here?

(Signature)

(Date)

If your parents/caregivers feel that you understand what the project is about, please give this form back to me.

[insert name here when research officer is appointed].

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor: Dr Hannah Badland, *hannah.badland@aut.ac.nz,* (09) 921 9999 ext 7630.

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC: Madeline Banda, *madeline.banda@aut.ac.nz*, (09) 921 9999 ext 8044.

Approved by the Auckland University of Technology Ethics Committee on *21 September 2007*, AUTEC Reference number *07/126*.

APPENDIX C: CONSENT FORM FOR THE URBAN STUDY: A NATIONAL AND INTERNATIONAL PROJECT (STUDY 1-2; CHAPTERS 3-4)

Participant Information Sheet

AUT UNIVERSITY TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

THE UNIVERSITY OF AUCKLAND NEW ZEALAND Te Whare Wānanga o Tāmaki Makaurau

UNIVERSITY of OTAGO Te Whare Wānanga o Otāgo

Massey University

Project Title**: The URBAN study: A national and international project.**

Project supervisor**:** **Dr Hannah Badland** Researcher**: Research Officer [Name to be inserted when appointed]**

- ☐ I have read and understood the information provided about this research project in the Information Sheet dated 15th July 2007.
- ☐ I have had an opportunity to ask questions and to have them answered.
- ☐ I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- ☐ I am not suffering from any severe walking mobility restrictions.
- ☐ I am fluent in the English language.
- ☐ I agree to wearing an accelerometer and completing the questionnaire.
- ☐ I agree to take part in this research.
- ☐ I wish to receive a copy of the report from the research (please tick one): Yes ☐ No ☐

Participant's signature: ____

Participant's name: ____

Participant's Contact Details (if appropriate):

____

____

____

Date: ____

Approved by the Auckland University of Technology Ethics Committee on 21 September 2007 AUTEC Reference number 07/126

Note: Participants should retain a copy of this form

APPENDIX D: APPROVAL LETTER FROM ETHICS COMMITTEE FOR THE URBAN STUDY: A NATIONAL AND INTERNATIONAL PROJECT (STUDY 1-2; CHAPTERS 3-4)

MEMORANDUM

Auckland University of Technology Ethics Committee (AUTEC)

To: Grant Schofield
From: **Madeline Banda** Executive Secretary, AUTEC
Date: 21 September 2007
Subject: Ethics Application Number 07/126 **Built environments, physical activity and obesity: a national and international study (BEPAOS).**

Dear Grant

Thank you for providing written evidence as requested. I am pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC) at their meeting on 13 August 2007 and that as the Executive Secretary of AUTEC I have approved your ethics application. This delegated approval is made in accordance with section 5.3.2.3 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement at AUTEC's meeting on 8 October 2007.

Your ethics application is approved for a period of three years until 21 September 2010.
I advise that as part of the ethics approval process, you are required to submit to AUTEC the following:

- A brief annual progress report indicating compliance with the ethical approval given using form EA2, which is available online through *http://www.aut.ac.nz/about/ethics*, including when necessary a request for extension of the approval one month prior to its expiry on 21 September 2010;
- A brief report on the status of the project using form EA3, which is available online through *http://www.aut.ac.nz/about/ethics*. This report is to be submitted either when the approval expires on 21 September 2010 or on completion of the project, whichever comes sooner;

It is also a condition of approval that AUTEC is notified of any adverse events or if the research does not commence and that AUTEC approval is sought for any alteration to the research, including any alteration of or addition to the participant documents involved.

You are reminded that, as applicant, you are responsible for ensuring that any research undertaken under this approval is carried out within the parameters approved for your application. Any change to the research outside the parameters of this approval must be submitted to AUTEC for approval before that change is implemented.

Please note that AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to make the arrangements necessary to obtain this. Also, should your research be undertaken within a jurisdiction outside New Zealand, you will need to make the arrangements necessary to meet the legal and ethical requirements that apply within that jurisdiction.

To enable us to provide you with efficient service, we ask that you use the application number and study title in all written and verbal correspondence with us. Should you have any further enquiries regarding this matter, you are welcome to contact Charles Grinter, Ethics Coordinator, by email at charles.grinter@aut.ac.nz or by telephone on 921 9999 at extension 8860.

On behalf of the Committee and myself, I wish you success with your research and look forward to reading about it in your reports.

Yours sincerely

Madeline Banda
Executive Secretary
Auckland University of Technology Ethics Committee

APPENDIX E: PARTICIPANT INFORMATION SHEET FOR THE POWER OF PLAY: A SCHOOL-BASED INTERVENTION TO INCREASE PHYSICAL ACTIVITY AMONG NEW ZEALAND PRIMARY SCHOOL CHILDREN (STUDY 4-6; CHAPTERS 5-7)

Participant Information Sheet

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Date Information Sheet produced: 11th June 2007

Project Title: A school based intervention to increase physical activity among New Zealand primary school children: The power of play.

An Invitation
You and your child are invited to join in the Power of Play project at XXX School. Thank you for considering joining in this research project. Please read the following information sheet carefully before deciding to take part. If you have any questions please ask.

I am Les Mc Grath a post graduate student at AUT University.

Les Mc Grath
Division of Sport and Recreation,
Faculty of Health Sciences,
Akoranga Campus,
Auckland University of Technology,
Private Bag 92006, Auckland 1020.
Email: Alanles@xtra.co.nz

The Power of Play project is part of my study towards a Master of Health Science degree. I will be researching the play of decile 4 primary school children to better understand how play periods at primary schools play a part in children's daily exercise.

Your child's involvement in this study is voluntary. A child may not join in this study without the approval of a parent or legal guardian and the consent of the child. You or your child are free to withdraw consent and stop at any time without changing your present and / or future involvement with the school or AUT University. Your consent to allow your child to join in the Power of Play project will be indicated by signing the consent form provided.

What is the purpose of this research?
The Power of Play project is attempting to answer two questions:

1. How much daily exercise do decile 4 primary school children get during play periods at school?
2. Will additional play periods increase the amount of exercise primary school children undertake daily?

On completion of this research project I will have completed a Masters in Health Science. I have already completed a post graduate degree in Health Science. In addition, the findings of this study will be published in an international journal such as the European Journal of Public Health.

How was I chosen for this invitation?

Your child's primary school was invited to participate in the Power of Play project. The school representatives consented to the Stanhope Road School participating in the Power of Play project.

The Power of Play project is a school wide programme and all children at the school have been invited to join. Only Year 5 children will be invited to join in measurements necessary for the study. A selection of Year 5 children consenting to join in the study will have physical activity measurements taken.

What will happen in this research?
The Power of Play project will be in place for 6 weeks at XXX School in term three during which time the following activities will take place.

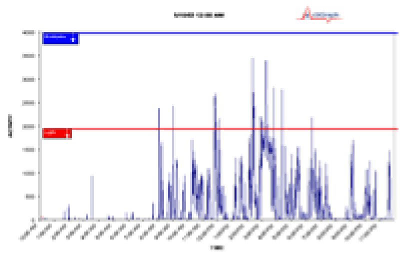
1. The school gates will officially open at 8am in term three to allow the children to join in a variety of self chosen game activities free of charge.
2. Play equipment such as sports balls and bats, frisbees, hula hoops, skipping ropes etc will be provided. Play equipment for female and male children will be available. Children may choose to join in these play sessions as they wish. The children can attend any play session on any day.
3. The researcher and assistants will supervise children during before school play periods.
4. Play periods will be videotaped to record the number of children active at play.
5. The new play periods will be promoted in school newsletters.
6. Also, parents will be invited to attend school assembly's run by the children on ways to increase physical activity, including walking to school and attending the before school play periods.
7. At the end of the study the school representatives, parents and legal guardians will meet to share information, discuss issues and consider the continuing the Power of Play program. Those attending the meeting will be requested to complete a post evaluation questionnaire and answer a set of questions which are attached.
8. Joining in the before school play period will be available to all students. Children may play any game or join in any activity they wish to. Children will play at a level which matches their fitness and comfort as in any school play period. The play periods are supervised for safety.

Measurement of physical activity levels
All 9 year olds at the school will be invited to participate in research measurements. The following information will be collected from students giving consent: age, ethnicity, gender , height, weight, % body fat and body-mass index.

A selection of Year 5 children with consent will be assessed for physical activity levels for 7 days on three different weeks using an accelerometer. Children will be required to wear the accelerometer around their waist from the time they wake until the time they go to bed at night.

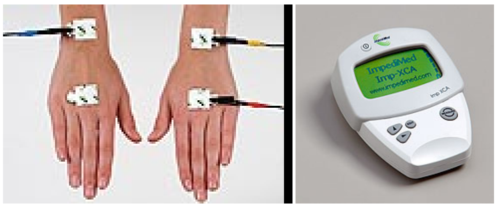
The accelerometers are very small (38mm x 37mm x 18mm) and lightweight (27gm). Children can easily fit them and hardly notice they are wearing them. Parents may need to remind children to wear the accelerometers. Children as young as 6 years old can easily fit and wear the accelerometers.

The accelerometers store the number of activity counts or movements children make when they are active. The researcher downloads the stored activity counts on to a personal computer for analysis. The software provides graphs of your children's physical activity levels.



The graph shows the time when a child is active. The higher the spike on the graph the more active your child has been. This information and any data collected will be available to parents or legal guardians. However, the information collected is confidential between the researchers, child and parent or legal guardian and will not be disclosed to any other persons.

Measuring % Body fat
A bio impedance analyser will be used to measure child's lean body mass. A very small electric current which is not detectable by children is passed through electrodes in the hand and used to measure lean body mass. All measurements are taken in private with two researchers present at all times.



Fat mass is calculated by subtracting the lean body mass from the child's body weight. The measurement is safe, accurate, fast and easy.

What are the discomforts and risks?
Children are expected to play in a normal manner and will experience levels of discomfort and risk associated with any normal school play period. Children will join (or not join) in games at a level of activity that they choose to match their fitness and comfort. Children may be embarrassed or upset when having body weight, body fat and other measurements taken so these measurements are taken in private.

How will these discomforts and risks be alleviated?
Discomforts and risks of harm to the children at play are the same as any play period at school. Children choose to play or not, they decide which games and activities they want to participate in. Children also decide their level of physical exertion as they play provided that children play in a safe manner and within normal playground rules. To minimise risk of harm to children joining in the study even further (i) each play period will be supervised to a standard consistent with school policy, (ii) at least one play supervisor will be present at all times, (iii) play supervisors will have a current first aid certificate, (iv) all play equipment will meet New Zealand safety standards, (v) all persons collecting measurements will be experienced, (vi) all measurements will be taken privately with two researchers present at all times. A female researcher will be available to perform measurements on females. Participants will be able to choose which researcher they would like to take the measurements. (vii) All information will be confidential between the child, parent or legal guardian and all researchers.

What are the benefits?
Children who are physically active daily walking to school, being involved in sports and playing have a reduced possibility of developing risk factors associated with cardiovascular disease and diabetes. The Power of Play project is designed to increase the physical activity levels of primary school children. Parents or guardians have the assurance that children are able to play in a safe, supervised environment. If parents or guardians need to be somewhere early in the morning children can be dropped off early with peace of mind. Children will be benefiting from increased play and exercise. If valid scientific data can be collected that shows the Power of Play project is capable of increasing physical activity in primary school children then the program can be extended to continue after research is completed.

What compensation is available for injury or negligence?
Compensation is available through the Accident Compensation Corporation within its normal limitations.

How will my privacy be protected?
All personal information, questions, answers and results from this study will be treated as confidential and will be handled in accordance with the principles of the Privacy Act 1993. The identity of children will be protected at all stages of the project. Information will be kept secure by the following processes.

- Individuals involved in collecting information will be required to sign a confidentiality agreement.
- Identifying information will be removed from documents.
- Forms will be kept in a secure location at AUT and separately from data collected.
- Data will be entered and stored directly onto password protected electronic databases.
- Parents and legal guardians of children will have access to all stored information relating to your child.
- Only information necessary for the purposes of this study will be collected.
- Data shall not be shared with any other third party that is not directly involved with the project.

What are the costs of participating in this research?
There are no monetary costs to parents in the Power of Play project. Children will be required for approximately, 15 minutes for the taking of measurements. Over the 7 days of accelerometer measurements children will also be required to attach the accelerometer themselves (a task easily performed by 9 year olds). The time taken to attach or remove the accelerometer is only a few seconds.

What opportunity do I have to consider this invitation?
The decision to join in the study can be made at any time before the start of the Power of Play project which will begin in 14 days time.

How do I agree to participate in this research?
Your consent to allow your child to join in the Power of Play project will be indicated by signing the consent form attached. Signing the consent form indicates that you have given your consent freely to join the Power of Play project and that there has been no coercion or inducement to allow your child to join. Full consent for your child to join in the Power of Play project is conditional on your child also agreeing to join.
Your child joins the study only if they wish too. A child may not join in this study without the approval of a parent or legal guardian and the consent of the child. You or your child are free to withdraw consent and stop at any time without changing your present and / or future involvement with the school or AUT University.

Will I receive feedback on the results of this research?
Parents or legal guardians will receive a short report at the end of the study. The reports will include a summary of findings. Three weeks will be necessary to collect information and write the reports. Stakeholders including school representatives, legal guardians and parents will be invited to a meeting to share information and discuss issues. No personal information or personal results will be discussed or divulged at the meetings. Individual reports and an invitation to attend meetings will be posted to parents or legal guardians one week prior to the meeting.

What do I do if I have concerns about this research?
Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor:

Dr Erica Hinckson, erica.hinckson@aut.ac.nz, 921 9999 extension 7224

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, *madeline.banda@aut.ac.nz* , 921 9999 ext 8044.

Whom do I contact for further information about this research?

Researcher contact details:

Les Mc Grath
Division of Sport and Recreation,
Faculty of Health Sciences,
Akoranga Campus,
Auckland University of Technology,
Private Bag 92006, Auckland 1020.
Email: Alanles@xtra.co.nz

Project Supervisor's Contact Details:

Dr Erica Hinckson,
Senior Lecturer,
Division of Sport and Recreation,
Faculty of Health Sciences,
Akoranga Campus,
Auckland University of Technology,
Private Bag 92006, Auckland 1020.
Phone 921 9999 extension 7224
Email: erica.hinckson@aut.ac.nz

Associate Professor Grant Schofield,
Division of Sport and Recreation,
Faculty of Health Sciences,
Akoranga Campus,
Auckland University of Technology,
Private Bag 92006, Auckland 1020.
Phone 921 9999 extension 7307,
Email: grant.schofield@aut.ac.nz

Approved by the Auckland University of Technology Ethics Committee on 16th April 2007, AUTEC Reference number 06/214.

APPENDIX F: CHILD INFORMATION SHEET AND ASSENT FORM FOR THE POWER OF PLAY: A SCHOOL-BASED INTERVENTION TO INCREASE PHYSICAL ACTIVITY AMONG NEW ZEALAND PRIMARY SCHOOL CHILDREN (STUDY 4-6; CHAPTERS 5-7)

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

A SCHOOL BASED INTERVENTION TO INCREASE PHYSICAL ACTIVITY AMONG NEW ZEALAND PRIMARY SCHOOL CHILDREN: THE POWER OF PLAY.

INFORMATION SHEET AND ASSENT FORM FOR CHILDREN

(parent/caregivers please read to children)

This form will be kept for a period of 6 years

Hello – my name is Les Mc Grath.

I would like to spend time at XXX Primary School. I will be at your school handing out play equipment and supervising play periods everyday in term three.

Is that okay? Please circle **YES** or circle **NO** .

I also want to use a video camera to record all the children while they play.

Is that okay? Please circle **YES** or circle **NO** .

I am learning about how much exercise children get when they play. This small computer can measure exercise.

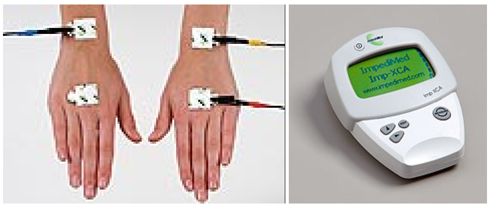
Would you like to wear one so you can learn how much exercise you get?

Please circle YES or circle NO .

Will it be okay to measure how tall you are and how much you weigh?

Please circle YES or circle NO .

A machine like this one can measure how much body fat you have. It doesn't hurt and many children have been measured before.



I will need to connect wires to you to measure your body fat.

Will that be okay? Please circle YES or circle NO .

If you would like to help me with my learning about exercise please circle YES or circle NO .

This is a photograph of me. I will also wear a badge with my name on it, Les Mc Grath, when I am at your school.

If you feel that you understand what the project is about please give this form back to your teacher at school tomorrow.

Thank you for completing this form – will you ask your parent / caregiver to sign here

(Child's name)

(Parent / Caregiver Signature)

(Date)

Les Mc Grath Researcher

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor,

Dr Erica Hinckson, erica.hinckson@aut.ac.nz, 921 9999 extension 7224

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, *madeline.banda@aut.ac.nz* , 921 9999 ext 8044.

Approved by the Auckland University of Technology Ethics Committee on 16th April 2007 AUTEC Reference number 06/214

APPENDIX G: CONSENT TO PARTICIPATION IN THE POWER OF PLAY: A SCHOOL-BASED INTERVENTION TO INCREASE PHYSICAL ACTIVITY AMONG NEW ZEALAND PRIMARY SCHOOL CHILDREN (STUDY 4-6; CHAPTERS 5-7)

Parent / Guardian Consent form

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project Title**: A school based intervention to increase physical activity among New Zealand primary school children: The power of play.**

Project supervisor**: Dr Erica Hinckson** Researcher**: Les McGrath**

☐ I have read and understood the information provided about this research project in the Information Sheet dated 11th June 2007

☐ I have had an opportunity to ask questions and to have them answered.

☐ I understand that the post study evaluation discussion will be audio-taped and transcribed.

☐ I understand that I may withdraw my child/children and/or myself or any information that we have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.

☐ If my child/children and/or I withdraw, I understand that all relevant information about my child/children will be destroyed.

☐ I agree to my child/children taking part in this research.

☐ I wish to receive a copy of the report from the research (please tick one): Yes ☐ No ☐

Child / children's name: ______________________________

Parent / guardian name: ______________________________

Parent / guardian signature: ______________________________

Parent / guardian Address: ______________________________

____

____

Date: ______________________________

Approved by the Auckland University of Technology Ethics Committee on 16th April 2007 AUTEC Reference number 06/214

Note: Participants should retain a copy of this form

APPENDIX H: APPROVAL LETTER FROM ETHICS COMMITTEE FOR THE POWER OF PLAY: A SCHOOL-BASED INTERVENTION TO INCREASE PHYSICAL ACTIVITY AMONG NEW ZEALAND PRIMARY SCHOOL CHILDREN (STUDY 4-6; CHAPTERS 5-7)

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

MEMORANDUM

Auckland University of Technology Ethics Committee (AUTEC)

To: Erica Hinckson
From: **Madeline Banda** Executive Secretary, AUTEC
Date: 31 March 2007
Subject: Ethics Application Number 06/214 **A school based intervention to increase physical activity among New Zealand primary school children: the power of play.**

Dear Erica

Thank you for providing written evidence as requested. I am pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC) at their meeting on 13 November 2006 and that as the Executive Secretary of AUTEC I have approved your ethics application. This delegated approval is made in accordance with section 5.3.2.3 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement at AUTEC's meeting on 16 April 2007.

I advise that as part of the ethics approval process, you are required to submit to AUTEC the following:

- A brief annual progress report indicating compliance with the ethical approval given using form EA2, which is available online through *http://www.aut.ac.nz/research/ethics*, including when necessary a request for extension of the approval one month prior to its expiry on 31 March 2010;
- A brief report on the status of the project using form EA3, which is available online through *http://www.aut.ac.nz/research/ethics*. This report is to be submitted either when the approval expires on 31 March 2010 or on completion of the project, whichever comes sooner;

It is also a condition of approval that AUTEC is notified of any adverse events or if the research does not commence and that AUTEC approval is sought for any alteration to the research, including any alteration of or addition to the participant documents involved.

You are reminded that, as applicant, you are responsible for ensuring that any research undertaken under this approval is carried out within the parameters approved for your application. Any change to the research outside the parameters of this approval must be submitted to AUTEC for approval before that change is implemented.

Please note that AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to make the arrangements necessary to obtain this. Also, should your research be undertaken within a jurisdiction outside New Zealand, you will need to make the arrangements necessary to meet the legal and ethical requirements that apply within that jurisdiction.

To enable us to provide you with efficient service, we ask that you use the application number and study title in all written and verbal correspondence with us. Should you have any further enquiries regarding this matter, you are welcome to contact Charles Grinter, Ethics Coordinator, by email at charles.grinter@aut.ac.nz or by telephone on 921 9999 at extension 8860.

On behalf of the Committee and myself, I wish you success with your research and look forward to reading about it in your reports.

Yours sincerely

Madeline Banda
Executive Secretary
Auckland University of Technology Ethics Committee
Cc: Leslie Julian McGrath alanles@xtra.co.nz

APPENDIX I: PARTICIPANT INFORMATION SHEET FOR THE ACTICAL PHYSICAL ACTIVITY PROJECT: THE UTILITY OF THE ACTICAL ACCELEROMETER STEP COUNT FUNCTION IN FREE LIVING CONDITIONS

Participant Information Sheet

Date Information Sheet produced: 20th November 2010

Project Title: Actical physical activity project: the utility of the Actical accelerometer step count function in free living conditions project

An Invitation

You and your child are invited to join in the Actical Physical Activity Project at XXX School. Thank you for considering joining in this research project. Please read the following information sheet carefully before deciding to take part. If you have any questions please ask.

I am Les Mc Grath a PhD candidate at AUT University.

Les Mc Grath
School of Sport and Recreation,
Faculty of Health Sciences,
Akoranga Campus,
Auckland University of Technology,
Private Bag 92006, Auckland 1020.
Phone 921 9999 extension 7848
Email: lmcgrath@aut.ac.nz

The Actical Physical Activity Project is part of my study towards a Doctor of Philosophy degree. I will be researching the amount of physical activity Year 2 & 3 and Year 5 & 6 primary school children get at play, walking, running and doing class work as measured by direct observation using videotaped recordings of children compared to three activity monitors which are small computers that measure children's physical activity levels. The study will examine the differences in the four methods for recording children's physical activity levels.

Your child's involvement in this study is voluntary. A child may not join in this study without the approval of a parent or legal guardian and the consent of the child. You or your child are free to withdraw consent and stop at any time without changing your present and / or future involvement with the school or AUT University. Your consent to allow your child to join in the Actical Physical Activity Project will be indicated by signing the consent form provided.

What is the purpose of this research?
Nationally and internationally researchers are continually assessing and revising ways to measure children's physical activity levels. A new model Actical Accelerometer has been designed to measure children's physical activity levels but the accuracy of this new accelerometer is unknown. This project is designed to answer two questions about the Actical accelerometer:

1. Does the Actical Accelerometer step count function reliably measure the number of steps children take in free play, walking, running and doing class work?

2. Does the Actical Accelerometer accurately classify children's physical activity into sedentary, light, moderate and vigorous activity?

This research project is one of five studies that I will conduct to complete a Doctor of Philosophy. I have already completed studies for a post graduate degree in Health Science. In addition, the findings of this study will be published in an international journal such as the Pediatric Exercise Science Journal.

How was I chosen for this invitation?
Your child's primary school was invited to participate in the Actical Physical Activity Project. The school representatives consented to the XXX School participating in the Actical Physical Activity Project.

The Actical Physical Activity Project is inviting Year 2 & 3 and Year 5 & 6 children to join in measurements necessary for the study and to wear an Actical Accelerometer, Actigraph Accelerometer and ActivPAL activity monitor while at free play, walking, running or doing class work. Children will be videotaped performing each of these activities. All Year 2 & 3 and Year 5 & 6 children consenting to join in the study will have physical activity measurements taken.

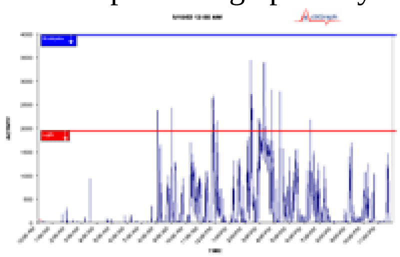
What will happen in this research?
Parents and whanau are invited to be present when measurements on their child are undertaken.

The Actical Physical Activity Project will take place over 2 days at XXX School in term 1. All Year 2 & 3 and Year 5 & 6 children at the school will be invited to participate in the study. Children will be required to wear an elastic strap with the accelerometers attached around their waists and an ActivPAL monitor on their mid thigh attached using elastic sports bandages during school hours for two school days. Children will also be videotaped while at play, walking, running and doing class work.

Actical Accelerometer   Actigraph Accelerometer   ActivPAL Activity Monitor
Both accelerometers are very small (38mm x 37mm x 18mm) and lightweight (27gm). ActivPAL is equally small (53mm x 35mm x 7mm) and only weighs 15 grams.

Children hardly notice they are wearing the devices. Researchers will assist children with the fitting of accelerometers and monitors.

The accelerometers store the number of activity counts or movements children make and count the number of steps a child takes when they are active. The researcher downloads the stored activity counts and step counts on to a computer for analysis. The software provides graphs of your children's physical activity levels.



The graph shows the time when a child is active. The higher the spike on the graph the more active your child has been. This information and any data collected will be available to parents or legal guardians. However, the information collected is confidential between the researchers, child and parent or legal guardian and will not be disclosed to any other persons.

The Actical accelerometer and ActivPAL monitor records the amount of steps taken each minute of the day and the number of activity counts or movements' children make every 15 seconds of the day. The ActivPAL also measures time spent sitting, standing and walking. This provides an accurate measurement of children's physical activity in real time which will be matched with videotaped recordings of children at play, walking running and doing class work. The result will be a record of the amount of physical activity accumulated in different activities.

The different activities will include the following. One hour of classroom activities will be videotaped and coded into descriptions of the activity being performed e.g. seated in chair writing, seated on floor listening, standing listening, standing walking or standing running.

Children will also perform 2 minute walking at 3.0, 4.0, 5.0, 6.0 km/h, speeds which range from slow walking to fast walking for children. Also children will perform 40 metre running tests at speeds, which range from slow running to fast running for children, approximately 2, 3, 4, and 5 metres per second and at each child's fastest running speed. Researchers will use a global positioning system (GPS) monitor and timing lights to measure and pace the speed children will walk and run. The running and walking speeds are well within the normal abilities of children of these ages.

Children will also be videotaped during a normal physical education class. All free play, walking, running and class work will be videotaped to compare the actual steps children take with Actical Accelerometer step counts recorded. The videotapes will also be used to classify the intensity of activity sedentary, light, moderate or vigorous and compare these with those classified by the Actical Accelerometer. On completion of this analysis all videotapes and reproductions will be erased.

In addition the following information will be collected from students giving consent:

- Age, Ethnicity, Gender, Height, Weight, Waistline, Body Mass Index (BMI).

What are the discomforts and risks?

The Children may be embarrassed or upset when having body weight and other measurements taken so these measurements are taken separate from other children and the results are kept private. A female and male researcher will be present when any measurements are taken.

How will these discomforts and risks be alleviated?

Discomforts and risks of harm to the children are the same for any normal school day or weekend day. Supervision and minimisation of risk are under the control of the school.
To minimise risk of harm to children joining in the study even further (i) all persons collecting measurements will be experienced, (ii) all measurements will be taken separate from other children and the results are kept private with two researchers present at all times. A female researcher will perform measurements on females. Participants will be able to choose which researcher they would like to take the measurements. (iii) All information will be confidential between the child, parent or legal guardian and all researchers. (iv) Parents and whanau are invited to be present when measurements on their child are undertaken.

What are the benefits?

Children who are physically active daily; walking to school, doing chores, being involved in sports, playing and spending minimal time (less than two hours) using electronic media (TV, computer games and console games) have a reduced possibility of developing risk factors associated with cardiovascular disease and diabetes.

Researchers are interested in determining accurately how much physical activity children accumulate in exercise, sports, play and daily living activities like class work, walking and running.

The Actical Physical Activity Project is designed to determine how much physical activity is associated with each of these activities and if the Actical Accelerometer is measuring this activity accurately. If valid scientific data can be collected that determines what level of physical activity is associated with various children's activities then researchers can make appropriate recommendations for children for the maintenance of good health.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will my privacy be protected?

All personal information, questions, answers and results from this study will be treated as confidential and will be handled in accordance with the principles of the Privacy Act 1993. The identity of children will be protected at all stages of the project. Information will be kept secure by the following processes.

- Individuals involved in collecting information will be required to sign a confidentiality agreement.
- Identifying information will be removed from documents.

- Forms will be kept in a secure location at AUT and separately from data collected.
- Data will be entered and stored directly onto password protected electronic databases.
- Parents and legal guardians of children will have access to all stored information relating to your child.
- Only information necessary for the purposes of this study will be collected.
- Data will not be shared with any other third party that is not directly involved with the project.

What are the costs of participating in this research?
There are no monetary costs to parents in the Actical Physical Activity Project. Children will be required for approximately 15 minutes for the taking of measurements. All measurement information collected and tasks performed by the children will occur during normal school hours. Over the measurement period of two school days children will also be required to wear an accelerometer. These will be correctly fitted with the assistance of the researcher and research assistants.

What opportunity do I have to consider this invitation?
The decision to join in the study can be made at any time before the start of the Actical Physical Activity Project which will begin in 14 days time.

How do I agree to participate in this research?
Your consent to allow your child to join in the Actical Physical Activity Project will be indicated by signing the consent form attached. Signing the consent form indicates that you have given your consent freely to join the Actical Physical Activity Project and that there has been no coercion or inducement to allow your child to join. Full consent for your child to join in the Actical Physical Activity Project is conditional on your child also agreeing to join.

Your child joins the study only if they wish to. A child may not join in this study without the approval of a parent or legal guardian and the consent of the child. You or your child are free to withdraw consent and stop at any time without changing your present and / or future involvement with the school or AUT University.

Will I receive feedback on the results of this research?
Parents or legal guardians will receive a short report of their child's physical activity results within 2 weeks of completing the study measurements. The reports will include a preliminary summary of findings. Stakeholders including school representatives, legal guardians and parents will be offered copies of journal articles about the study. No personal information or personal results will be discussed or divulged in the journal articles. A second more comprehensive summary of findings will be forwarded to parents or legal guardians on completion of the journal article. Completion of the journal article is expected within six months of completion of children's measurements.

What do I do if I have concerns about this research?
Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr Erica Hinckson, erica.hinckson@aut.ac.nz, 921 9999 extension 7224

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, *madeline.banda@aut.ac.nz* , 921 9999 ext 8044.

Whom do I contact for further information about this research?

Researcher contact details:

Les Mc Grath
Division of Sport and Recreation,
Faculty of Health Sciences,
Akoranga Campus,
Auckland University of Technology,
Private Bag 92006, Auckland 1020.
Email: Alanles@xtra.co.nz

Project Supervisor's Contact Details:

Dr Erica Hinckson,
Senior Lecturer,
School of Sport and Recreation,
Faculty of Health Sciences,
Akoranga Campus,
Auckland University of Technology,
Private Bag 92006, Auckland 1020.
Phone 921 9999 extension 7224
Email: erica.hinckson@aut.ac.nz

Professor of Exercise Science,
Dr Will Hopkins,
School of Sport and Recreation,
Institute of Sport & Recreation Research,
Akoranga Campus,
Auckland University of Technology,
Private Bag 92006, Auckland 1020.
Phone 921 9793,
Email: will.hopkins@aut.ac.nz

Approved by the Auckland University of Technology Ethics Committee on 25th February 2009, AUTEC Reference number 08/262.

APPENDIX J: CHILD INFORMATION SHEET AND ASSENT FORM FOR THE ACTICAL PHYSICAL ACTIVITY PROJECT: THE UTILITY OF THE ACTICAL ACCELEROMETER STEP COUNT FUNCTION IN FREE LIVING CONDITIONS

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

ACTICAL PHYSICAL ACTIVITY PROJECT:

ASSENT FORM FOR CHILDREN

(parent/caregivers please read to children)

This form will be kept for a period of 6 years

Hello – my name is Les Mc Grath.

I would like to spend time at XXX Primary School. I will be at your school to do a study on how much exercise children get during different activities at school.

Is that okay? Please circle YES or circle NO.

I am learning about how much exercise children get when they play, walk, run or do class work. These small computers can measure how long you sit, stand, walk and run.

Would you like to wear them so you can learn how much time you spend sitting, standing, walking and running?

Please circle YES or circle NO.

The small computers are called accelerometers. I will be asking children to wear them while they play, walk, run or do class work.

Would you like to wear one while you play, walk, run or do class work?

Please circle **YES** or circle **NO** .

Will it be okay to measure your waistline, how tall you are and how much you weigh?

Please circle **YES** or circle **NO** .

I will also need to videotape children while they play, walk, run or do class work.

Will it be okay to videotape you while you play, walk, run or do class work?

Please circle **YES** or circle **NO** .

Would you like to help me with my learning about how much exercise children get when they play, walk, run or do class work?

Please circle **YES** or circle **NO** .

This is a photograph of me. I will also wear a badge with my name on it, Les Mc Grath, when I am at your school.

If you feel that you understand what the project is about please give this form back to your teacher at school tomorrow.

Thank you for completing this form – will you ask your parent / caregiver to sign here

(Child's name)

(Parent / Caregiver Signature)

(Date)

Les Mc Grath (Researcher)

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor,

Dr Erica Hinckson, erica.hinckson@aut.ac.nz, 921 9999 extension 7224

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, *madeline.banda@aut.ac.nz*, 921 9999 ext 8044.

Approved by the Auckland University of Technology Ethics Committee on 25th February 2009, AUTEC Reference number 08/262.

APPENDIX K: CONSENT TO PARTICIPATION IN THE ACTICAL PHYSICAL ACTIVITY PROJECT: THE UTILITY OF THE ACTICAL ACCELEROMETER STEP COUNT FUNCTION IN FREE LIVING CONDITIONS

Parent / Guardian Consent form

Project Title**: Actical physical activity project: the utility of the Actical accelerometer step count function in free living conditions.**

Project supervisor**:** **Dr Erica Hinckson and Professor Will Hopkins**
Researcher**:** **Les McGrath**

- ☐ I have read and understood the information provided about this research project in the Information Sheet dated 20th November 2010
- ☐ I have had an opportunity to ask questions and to have them answered.
- ☐ I understand that the researchers will analyse my child's physical activity levels by reviewing the videotaped recordings of my child while he or she plays, walks, runs or does class work.
- ☐ I permit the researcher to use the videotaped recordings that are part of this project and/or any drawings from them and any other reproductions or adaptations from them, either complete or in part, alone or in conjunction with any wording and/or drawings solely and exclusively for academic purposes only.
- ☐ I understand that the videotaped recordings will be used for academic purposes only and will not be published in any form outside of this project without my written permission.
- ☐ I understand that I may withdraw my child/children, videotaped images and/or myself or any information that we have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- ☐ If my child/children and/or I withdraw, I understand that all relevant information including videotaped recordings (if practicable) and transcripts, or parts thereof, will be destroyed.
- ☐ I agree to my child/children taking part in this research.
- ☐ I wish to receive a copy of the report from the research (please tick one): Yes ☐ No ☐

Child / children's name: ____

Parent / guardian signature: ____

Parent / guardian name: ____

Parent / guardian Address: ____
____

Date: ______________________________

Approved by the Auckland University of Technology Ethics Committee on 25th February 2009, AUTEC Reference number 08/262.

Note: Participants should retain a copy of this form

APPENDIX L: APPROVAL LETTER FROM ETHICS COMMITTEE FOR THE ACTICAL PHYSICAL ACTIVITY PROJECT: THE UTILITY OF THE ACTICAL ACCELEROMETER STEP COUNT FUNCTION IN FREE LIVING CONDITIONS

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

MEMORANDUM

Auckland University of Technology Ethics Committee (AUTEC)

To: Erica Hinckson
From: **Madeline Banda** Executive Secretary, AUTEC
Date: 25 February 2009
Subject: Ethics Application Number 08/262 **Actical physical activity project: the utility of the actical accelerometer step count function in free living conditions.**

Dear Erica
Thank you for providing written evidence as requested. I am pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC) at their meeting on 10 November 2008 and that the Chair of AUTEC has approved your ethics application. This delegated approval is made in accordance with section 5.3.2.3 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement at AUTEC's meeting on 9 March 2009.

I advise that as part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through *http://www.aut.ac.nz/about/ethics*. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 25 February 2012;
- A brief report on the status of the project using form EA3, which is available online through *http://www.aut.ac.nz/about/ethics*. This report is to be submitted either when the approval expires on 25 February 2012 or on completion of the project, whichever comes sooner;

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are reminded that, as applicant, you are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

Please note that AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to make the arrangements necessary to obtain this. Also, if your research is undertaken within a jurisdiction outside New Zealand, you will need to make the arrangements necessary to meet the legal and ethical requirements that apply within that jurisdiction.

When communicating with us about this application, we ask that you use the application number and study title to enable us to provide you with prompt service. Should you have any further enquiries regarding this matter, you are welcome to contact Charles Grinter, Ethics Coordinator, by email at charles.grinter@aut.ac.nz or by telephone on 921 9999 at extension 8860.

On behalf of the AUTEC and myself, I wish you success with your research and look forward to reading about it in your reports.

Yours sincerely

Madeline Banda
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Leslie Julian McGrath lmcgrath@aut.ac.nz