PHYSICAL ACTIVITY AND OBESITY IN CHILDREN: MEASUREMENT, ASSOCIATIONS, AND RECOMMENDATIONS

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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 (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Scott Duncan

Co-authored Works

Chapters 2-7 of this thesis are comprised of scientific papers that are either published or under review. The percentage contribution of each author is presented below.

Chapter 2: Pedometer Validity in Children

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Chapter 3: Pedometer Reactivity in Children

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Chapter 4: Weather and Pedometer Steps in Children

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Chapter 7: Correlates of Obesity in New Zealand Children

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Research Outputs

Listed below are the peer-reviewed publications and conference presentations that have resulted from this thesis, in addition to the publications currently under review. The original published versions of all papers are presented in Appendix A.

Peer-reviewed Publications

Duncan, J. S., Hopkins, W. G., Schofield, G. & Duncan, E. K. (2008). Effects of weather on pedometer-determined physical activity in children. *Medicine and Science in Sports and Exercise*, 40(8): 1432-1438.

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Duncan, J. S., Schofield, G., Duncan, E. K. & Hinckson, E. A. (2007). Effects of age, walking speed, and body composition on pedometer accuracy in children. *Research Quarterly for Exercise and Sport*, 78(5): 420-428.

Duncan, J. S., Schofield, G. & Duncan, E. K. (2007). Step count recommendations for children based on body fat. *Preventive Medicine*, 44(1): 42-44.

Duncan, J. S., Duncan, E. K., Schofield, G. & Rush, E. C. (2006). *Obesity in New Zealand Asian children*. In S. Tse, M. E. Hoque, K. Rasanathan, M. Chatterj, R. Wee, S. Garg, & Y. Ratnasabapathy (Eds.). Prevention, protection, and promotion. Proceedings of the Second International Asian Health and Wellbeing Conference, November 11, 13-14, pp. 66-72. Auckland, New Zealand: University of Auckland.

Duncan, J. S., Schofield, G. & Duncan, E. K. (2006). Pedometer-determined physical activity and body composition in New Zealand children. *Medicine and Science in Sports and Exercise*, 38(8): 1402-1409.

Duncan, J. S., Schofield, G., Duncan, E. K. & Rush, E. C. (2004). Measuring physical activity in New Zealand children: A population health perspective. *New Zealand Journal of Sports Medicine*, 32(4): 100-105.

Conference Presentations

Duncan, J. S., Schofield, G., Duncan, E. K. & Rush, E. C. (2006). *Correlates of excess body fatness in New Zealand children*. Paper presented at the Australasian Society for the Study of Obesity Conference, Auckland, New Zealand.

Duncan, J. S. (2006). *Obesity and New Zealand Asian children*. Invited presentation at the Second International Asian Health and Wellbeing Conference, Auckland, New Zealand.

Duncan, J. S. (2006). *Physical activity and body composition in primary-aged children*. Paper presented at the Maori and Indigenous Doctoral Conference, Auckland, New Zealand.

Duncan, J. S., Schofield, G. & Duncan, E. K. (2006). *Daily step count recommendations for children.* Poster presented at the Ninth International Congress of Behavioural Medicine, Bangkok, Thailand.

Duncan, J. S., Schofield, G., Duncan, E. K. & Rush, E. C. (2006). *Correlates of excess body fatness in New Zealand children*. Poster presented at the Tenth International Congress on Obesity, Sydney, Australia.

Duncan, J. S., Schofield, G., Duncan, E. K. & Rush, E. C. (2005). *Classifying childhood obesity in a multiethnic population: Comparisons among five major ethnic groups.* Paper presented at the Seventh International Symposium In Vivo Body Composition Studies, Southampton, UK.

Duncan J. S., Schofield, G. & Duncan, E. K. (2005). *Pedometer steps and body composition in New Zealand primary-aged children.* Paper presented at the Australian Conference of Science and Medicine in Sport, Melbourne, Australia.

Duncan, J. S., Schofield, G. & Duncan, E. K. (2005). *Pedometer-determined physical activity and active transport in New Zealand children*. Paper presented at the Agencies for Nutrition Action Conference, Christchurch, New Zealand.

Duncan, J. S., Schofield, G. & Duncan, E. K. (2005). *Children's reactivity to wearing sealed seven-day-memory pedometers.* Paper presented at the Australasian Society for Behavioural Health and Medicine Conference, Melbourne, Australia.

Duncan, J. S. (2005). *Overweight, obesity, and New Zealand Asian children*. Invited presentation at the Asian Women's Health Symposium, Auckland, New Zealand.

Duncan, J. S., Schofield, G. & Rush, E. C. (2003). *Measuring physical activity in New Zealand children*. Paper presented at the New Zealand Sports Medicine and Science Conference, Nelson, New Zealand.

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Abbreviations

%BF .... Percentage Body Fat
ANOVA .... Analysis of Variance
ANCOVA .... Analysis of Covariance
BIA .... Bioelectrical Impedance Analysis
BMC .... Bone Mineral Content
BMI .... Body Mass Index
CI .... Confidence Interval
CNS .... Children's Nutrition Survey
CVD .... Cardiovascular Disease
DEXA .... Dual-energy X-ray Absorptiometry
EE .... Energy Expenditure
FFM .... Fat-free Mass
FM .... Fat Mass
GPS .... Global Positioning System
GRF .... Ground Reaction Force
HR .... Heart Rate
ICC .... Intraclass Correlation Coefficient
IOTF .... International Obesity Taskforce
LDL .... Low Density Lipoprotein
LINZ .... Life in New Zealand
MDM .... Multiday Memory
NHANES .... National Health and Nutrition Survey
PAC-Q .... Physical Activity Questionnaire for Older Children
R .... Resistance
SAS .... Statistical Analysis Systems
SD .... Standard Deviation
SEE .... Standard Error of the Estimate
SES .... Socioeconomic Status
SPSS .... Statistical Package for the Social Sciences
WC .... Waist Circumference
WHR .... Waist-to-Hip Ratio
WHO .... World Health Organisation

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Abstract

Widespread increases in the prevalence of childhood obesity have raised the prospect of serious public health consequences in many countries. New Zealand is no exception; according to the most recent national estimates, approximately one in three children is overweight or obese.[152] As a consequence, an understanding of the specific risk factors that predict this condition in children is becoming increasingly important. It is generally accepted that the promotion of physical activity is a key strategy for reducing the risk of childhood obesity. However, there is limited information describing physical activity and its relationship with body fatness in young New Zealanders. The overall aim of this thesis was to gain insight into the associations between excess fatness and physical activity in New Zealand children from a diverse range of socio-demographic groups. Three related studies were conducted to achieve this aim: a large descriptive survey of obesity and physical activity patterns in primary-aged children, and two preceding studies which develop the methodology for objective assessment of physical activity in this population.

The first study provided the only validation data for the NL-2000 multiday memory (MDM) pedometer in children. In a sample of 85 participants aged 5-7 and 9-11 years, the NL-2000 offered similar accuracy and better precision than the widely used SW-200 pedometer (NL-2000: mean bias = -8.5 ± 13.3%; SW-200: mean bias = -8.6 ± 14.7%). The second study investigated reactivity to wearing pedometers over four 24-hour testing periods in 62 children aged 5-11 years. The sample was divided into two groups: one was given a full explanation of the function of the pedometer, while the other received no information prior to testing. The absence of significant differences in step counts between the first and last test periods indicated that there was no evidence of reactivity to this device for either preparation procedure.

The central study presented in this thesis was the measurement of physical activity, body composition, and dietary patterns in 1,226 children aged 5-12 years, from which four chapters (4-7) were derived. The sample was ethnically diverse, with 46.8% European, 33.1% Polynesian, 15.9% Asian, and 4.1% from other ethnicities. Physical activity levels over three weekdays and two weekend days were assessed using NL-2000 pedometers. Percentage body fat (%BF) was determined using hand-to-foot bioelectrical impedance analysis with a prediction equation previously developed for

New Zealand children. Waist and hip girths, height, and weight were measured using standard anthropometric techniques. Parent proxy questionnaires were used to assess demographic and lifestyle factors and pedometer compliance.

The first reported analyses of this dataset (Chapter 4) examined the effect of weather conditions on children's activity levels. In boys, a 10ºC rise in ambient temperature was associated with a 10.5% increase in weekday steps and a 26.4% increase in weekend steps. Equivalent temperature changes affected girls' step counts on weekdays only (16.2% increase). Precipitation also had a substantial impact, with decreases in weekday and weekend step counts during moderate rainfall ranging from 8.3% to 16.3% across all sex, age, and socioeconomic (SES) groups.

The aim of Chapter 5 was to understand the relationship between children's step counts and their body mass index (BMI), waist circumference (WC), and %BF. Mean step counts for this sample were $16{,}133 \pm 3{,}864$ (boys) and $14{,}124 \pm 3{,}286$ (girls) on weekdays, and $12{,}702 \pm 5{,}048$ (boys) and $11{,}158 \pm 4{,}309$ (girls) on weekends. Significant associations were detected between steps.day^{-1} and both WC and %BF, but not between steps.day^{-1} and BMI. The findings in Chapter 6 extended these results by estimating the number of steps required to reduce the risk of excess adiposity in children (16,000 and 13,000 steps.day^{-1} for boys and girls, respectively).

Finally, the study described in Chapter 7 examined the associations between excess adiposity and a series of demographic and lifestyle variables, providing the first assessment of body fat correlates in young New Zealanders. Our results indicated that children aged 11-12 years were 15.4 times more likely to be overfat (boys, %BF $\geq$ 25%; girls, %BF $\geq$ 30%) than those aged 5-6 years. In addition, the odds of overfat were 1.8 times greater in Asian children than in European children, and 2.7 times greater in the low SES group when compared with the high SES group. Three modifiable behaviours related to fat status were also identified: low physical activity, skipping breakfast, and insufficient sleep on weekdays. Clustering of these risk factors resulted in a cumulative increase in the prevalence of overfat.

CHAPTER 1

INTRODUCTION

Background

Obesity, a condition characterised by excessive accumulation of body fat, is a major risk factor for a variety of chronic disorders including cardiovascular disease (CVD), Type 2 diabetes, hypertension, osteoarthritis, cancer, and psychological problems such as reduced self-esteem and clinical depression.[255] Over the last ten years, substantial increases in the prevalence of overweight and obesity have been reported in many countries,[30,71,73] elevating obesity to one of the world's leading public health problems. In New Zealand, prevalence estimates indicate that we are following international trends: 20.7% of New Zealand adults were classified as obese in 2002, which represents a 22% increase since 1997, and an 88% increase since 1989.[153] The annual cost of obesity in New Zealand was conservatively estimated by the Ministry of Health to total $247.1 million between 2000 and 2001, with mortality rates double that attributed to the road toll.[151]

In recent years, media attention has focused on the emotive issue of childhood overweight and obesity, often with regard to bullying, discrimination, and other negative psychosocial aspects. However, the possibility that obese children will grow into obese adults is undoubtedly the greatest concern from a public health perspective. Longitudinal studies indicate that this concern is well founded, with older children and adolescents especially susceptible to persistent obesity.[28,33,42,80,90,176,195,251] Thus, initiatives that targeted obesity during childhood years will have flow-on effects for adults, providing the greatest long-term benefits for New Zealand. Indeed, overseas programmes designed to reduce obesity in children appear to achieve better long-term results than similar programmes for adults.[105]

Despite widespread opinion that New Zealand children are becoming fatter, it is imperative that public health policy is based on accurate scientific data rather than anecdotal evidence. The most extensive information to date was provided by the 2002 National Children's Nutrition Survey (CNS), which estimated that 21.3% of New Zealand children aged 5-12 years were overweight, with a further 9.8% obese.[152] Prevalence estimates were especially high for Pacific Island (33.4% overweight; 28.6%

obese) and Maori (25.1%; 16.2%) children when compared with those from the 'New Zealand European and Other' group (18.6%; 5.35%). Similar inequalities were observed in a sample of 2,273 Auckland children aged 5-11 years: overall, 14.3% were classified as obese, with Pacific Island and Maori children 2.8 and 1.8 times (respectively) more likely to be obese than European children.[229] These results are comparable to those reported overseas, suggesting that the dramatic increases in childhood overweight and obesity in USA,[162] UK,[39] and Australia[18] may also be occurring in New Zealand. Indeed, a study of Hawke's Bay children found that the risk of obesity in 2000 was 3.8 times greater than in 1989.[227] However, all of these studies used body mass index (BMI) – a simple measure of weight (kg) corrected for height (m^2) – as the screening tool for detecting overweight and obesity. This is despite uncertainty regarding its appropriateness as a proxy measure of body fatness in children. To put our current knowledge into perspective, it is important to have an understanding of the techniques available to assess obesity in paediatric populations.

Measuring Obesity in Children

Clinical studies utilise a variety of tools to examine body composition in children, including dual-energy x-ray absorptiometry (DEXA), underwater weighing, and isotope dilution. However, the substantial cost and technical expertise associated with these procedures precludes their use in population research. Anthropometric measures, such as BMI, girths, and skinfolds, provide less precise estimates of body composition, but are considerably more practical for use in field studies. Of these, BMI is undoubtedly the most widely used in population research. BMI is the simplest measurement to obtain, and can be directly compared with data from analogous studies. In large-scale surveys, individuals are commonly classified as overweight or obese according to their BMI. The World Health Organisation (WHO) has provided international BMI standards for measuring overweight and obesity in adult populations based on the risk of obesity-related illnesses for each BMI category.[255] However, this definition of overweight and obesity (BMI > 25 and 30 $kg.m^{-2}$ for men and women, respectively) is not suitable for use in paediatric populations due to the substantial changes in BMI that accompany development.

In paediatric populations, retrospective studies have shown that BMI tends to decrease to a nadir at approximately 4-6 years (following a short increase during infancy) before increasing until early adulthood: a phenomenon referred to as the 'adiposity rebound'.[178,246] The earlier the rebound, the greater the chance of a high BMI later in life, suggesting that BMI at ages 5-7 may be an acceptable indicator of body size during adulthood. Not surprisingly, age-specific BMI thresholds are generally used for defining weight status in children. Figure 1-1 illustrates the use of age-specific BMI percentiles when defining overweight and obesity.[123] Typically, individuals with a BMI greater than the 85th or 95th percentile of American reference data are considered overweight or obese (respectively). Although these criteria were relatively common in earlier studies, they hold less relevance for children outside USA. Furthermore, health risks associated with the 85th and 95th percentiles in boys and girls have yet to be investigated. In 2000, the International Obesity Taskforce (IOTF) developed a series of age- and sex-specific BMI cut-offs based on centile curves averaged from six countries that pass through a BMI of 25 and 30 kg.m^{-2} at age 18 years (Figure 1-2).[44] Although the averaging of discrete national datasets could be considered arbitrary, and 18 years as too young an age to represent 'adulthood', these cut-offs have quickly become the standard for defining overweight and obesity in children. Ideally, each population would develop its own set of cut-offs based on the specific dose-response relationship between BMI and associated health outcomes, or utilise a more accurate indicator of body fatness.

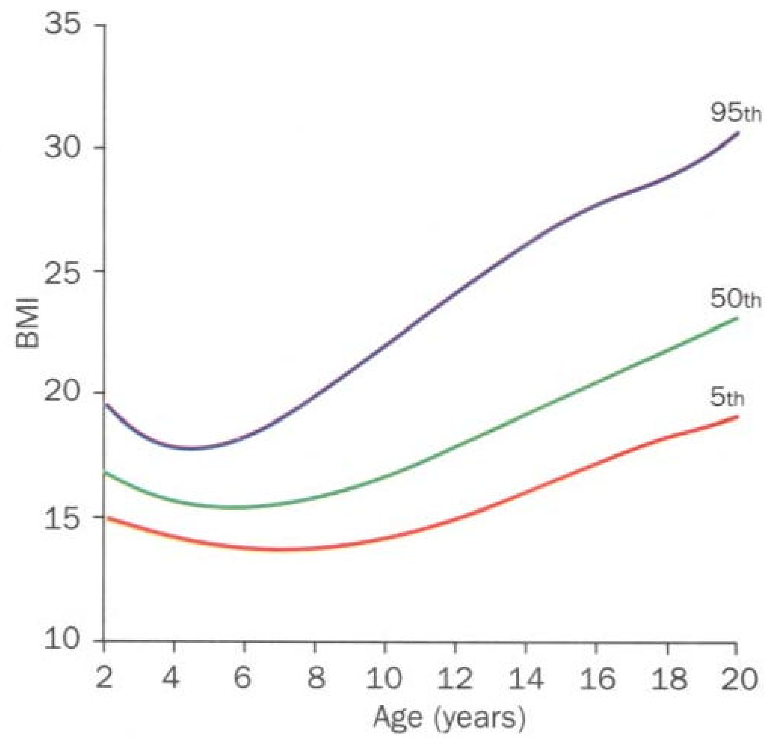

Figure 1-1. Example of age- and sex-specific BMI centile curves for American children.

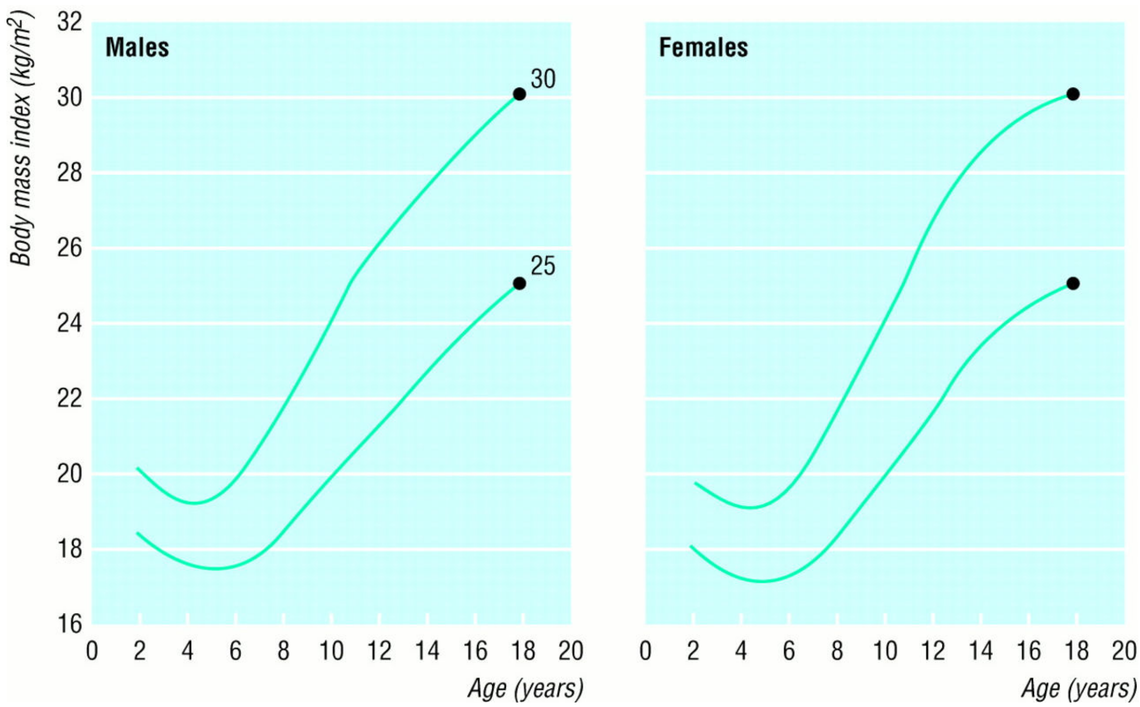

Figure 1-2. International age- and sex-specific BMI cut-off points for classifying overweight and obesity in children.[44]

Table 1-1 summarises the most recent estimates of BMI-determined overweight/obesity in children around the world. It should be noted that comparisons between some countries are difficult due to differences in the definition of overweight/obesity. Most have adopted the IOTF BMI cut-off points for young people, although some have classified overweight and obesity using percentiles of American reference data. Regardless, it is apparent that a common pattern is emerging within each population.

Table 1-1. International trends in BMI-determined overweight and obesity in children.

Country	Year	% Overweight/Obese	Classification
Australia[18]	1969 1985 1997	11% 12% 21%	BMI ≥ IOTF cut-offs
Brazil[242]	1974 1997	4% 14%	BMI ≥ IOTF cut-offs
Canada[213]	1984 1996	12% 32%	BMI ≥ IOTF cut-offs
China[242]	1991 1997	6% 8%	BMI ≥ IOTF cut-offs
Finland[116]	1977 1999	6% 13%	BMI ≥ 85th percentile
France[177,239]	1980 1996 2000	5% 13% 19%	1980-96: BMI ≥ 20 $kg.m^{-2}$ 2000: BMI ≥ IOTF cut-offs
Germany[122]	1975 1985 1995	11% 12% 19%	BMI ≥ 90th percentile
Japan[144]	1978 1988 1998	9% 13% 15%	BMI ≥ IOTF cut-offs
Netherlands[74]	1980 1997	10% 18%	BMI ≥ 90th percentile
***New Zealand*[152]**	**2002**	**21%**	**BMI ≥ IOTF cut-offs**
Spain[155]	1985 1995	15% 22%	BMI ≥ 95th percentile
Switzerland[256]	1965 1999	10% 32%	BMI ≥ 90th percentile
UK[39,55]	1974 1984 1994 2002	7% 8% 12% 25%	BMI ≥ IOTF cut-offs
USA[161,162]	1965 1980 1994 2004	4% 7% 11% 17%	BMI ≥ 95th percentile

A fundamental shortcoming of using BMI to classify overweight and obesity is its inability to distinguish between fat mass (FM) and fat-free mass (FFM). This limitation can lead to inaccuracies when using BMI to estimate body fatness in children whose body composition differs from the typical European phenotype. Rush *et al*.[182] found that for a fixed BMI, Maori and Pacific Island girls averaged 3.7% less body fat than New Zealand European girls. In contrast, Asian children tend to have more body fat than their European counterparts at the same BMI.[58,147] Thus, when assessing body composition in countries with diverse ethnic populations (e.g., New Zealand), the use of BMI in conjunction with a two-compartment model of body composition will provide a greater degree of accuracy.

Skinfold testing provides a measure of subcutaneous fat, and as such enables a partial distinction to be made between FM and FFM (and subsequently %BF). It involves raising a double fold of skin at various sites on the body and applying specialised callipers to measure the thickness. With the appropriate prediction equation, multisite skinfold procedures offer acceptable accuracy and precision for estimating %BF when compared with criterion standards.[26] In addition, comparing skinfolds from various sites provides an indication of the distribution of body fat. However, the invasive nature of this procedure tends to restrict the number of sites that can be measured in paediatric populations. Realistically, only the triceps skinfold can be tested in a school setting without risking excessive embarrassment or anxiety to participants. In this instance, inflated error through inter-individual variability in fat distribution greatly reduces the accuracy of skinfolds. Another potential shortcoming of this technique is the tendency of subcutaneous skinfold thickness to underestimate body fat in obese children, as relatively more fat is stored internally.[57] Moreover, the precision of skinfolds is highly dependent on the skill of the individual researcher. Large studies with numerous researchers, in particular, tend to suffer from with poor inter-rater reliability with this technique.

Another anthropometric measurement that is used as an estimate of the distribution of body fat is the waist circumference relative to the hip circumference, or waist-to-hip ratio (WHR). This information is of interest to public health researchers as the amount of fat stored around the trunk (central adiposity) appears to be a stronger predictor of health risk than total adiposity in both adults[121,125,126,131,186,192,250] and young people.[6,51,92,103,157,209] The New Zealand Ministry of Health considers that a WHR greater than 0.9 for men and 0.8 for women is unhealthy, independent of ethnicity.[151] However, a WHR criterion for implementation in paediatric populations has yet to be developed. Taylor *et al*.[208] suggested that the age-dependence of WHR renders it an unsuitable tool for young people, and instead recommended the use of waist circumference (WC) as an adequate indicator of central adiposity. While this approach has been supported in subsequent research,[98,132,141] WC is an absolute measure that does not take into account ethnic or genetic differences in body size. Clearly, further investigation is required before these WC thresholds are applied to multiethnic populations.

Bioelectrical impedance analysis (BIA) is an alternative procedure gaining popularity in epidemiological research due to its portability, user-friendliness, and accuracy for estimating both FM and FFM. It has been implemented in several large-scale studies, including the third National Health and Nutrition Survey (NHANES III) of more than 16,000 American adults and children,[40] and the Pathways Study, an obesity prevention programme for Native American children established in 41 elementary-level schools.[137] BIA estimates the FFM within an individual by recording the impedance or resistance to a small (< 1 mA) alternating (50 kHz) electrical current that is passed through the body. Put simply, the more muscle a person has, the more water they store and the easier the current will pass through their body (greater resistance corresponds to a lower FFM and consequently a higher %BF). However, the relationship between resistance and FFM is affected by differences in body size and shape. Calculating FFM from BIA requires the use of prediction equations that account for differences in height, weight, age, and sex.

A common criticism of BIA (applicable also to skinfold testing on limited sites) is the potential error associated with prediction equations for indirectly calculating %BF. Indeed, the use of generic manufacturers' equations to predict FFM and %BF can give variable results.[124] However, more direct estimates of body fat, such as DEXA and underwater weighing, can be used as criterion measures for the development of population-specific BIA prediction equations. Table 1-2 summarises the major publications in this area, including three from New Zealand.[61,182,228] These studies indicate that BIA can provide valid estimates of body fatness in child and adolescent populations across a range of age and ethnic groups. Furthermore, several studies have reported a high level of reliability when using BIA in young people.[8,102,228] Nevertheless, the study sample must be comparable to the reference population from which the FFM prediction equation was derived. In New Zealand, valid prediction equations are available for several ethnic groups. Rush *et al.*[182] utilised whole-body BIA to assess the body fatness of Auckland children and adolescents from three ethnic groups (NZ European, NZ Maori, and Pacific Island). A prediction equation for the estimation of FFM was developed that correlated closely with FFM obtained from deuterium dilution measurements of total body water ($r^2 = 0.96$, SEE = 2.6 kg). More recently, Duncan *et al.*[61] developed a valid equation for estimating the body composition of NZ Chinese and Indian children ($r^2 = 0.98$, SEE = 1.49 kg).

The ability of BIA to distinguish fat and lean mass using a non-invasive procedure makes this tool particularly useful for assessing body composition in paediatric populations. Although determination of %BF rather than BMI will naturally produce a greater degree of accuracy when classifying body fatness, an understanding of the association between %BF and health risk is required for equivalent %BF thresholds. In adults, the most commonly used definition of obesity (excluding BMI cut-off points) is a %BF greater than 25% for males and 30% for females.[255] There is less agreement about the %BF level that constitutes obesity in children. Higgins *et al* [96] has reported that CVD risk factors begin to appear at a %BF greater than 20% in American boys and girls. Other studies have suggested %BF thresholds that range between 20% and 30% depending on the sex of the child.[65,243,249] However, there are currently no age-specific %BF thresholds available for young people. Despite this shortcoming, BIA is becoming the preferred option for characterising the body composition in paediatric populations, providing a balance between cost, practicality, and accuracy.

Table 1-2. Validity of BIA for assessing body composition in paediatric populations.

Reference	Sample	Criterion Measure	Predictive Ability (r^2)	Cross-validation Measure
Bandini *et al.*[8]	Non-obese females aged 8-12 years (n = 132).	Deuterium dilution	0.93	Deuterium dilution
Deurenberg *et al.*[59]	Males and females aged 7-83 years (n = 827).	Underwater weighing	0.97 (7-15 y.o.)	Underwater weighing
Duncan *et al.*[61]	Chinese and Indian males and females aged 5-15 years (n = 79).	Deuterium dilution	0.98	Deuterium dilution
Gillis *et al.*[84]	Males and females ages 6-16 years (n = 67).	Underwater weighing	0.92	-
Houtkooper *et al.*[101]	Males and females aged 10-19 years (n = 94).	Deuterium dilution	0.95	Underwater weighing Deuterium dilution
Morrison *et al.*[156]	White (n = 65) and black (n = 61) females aged 6-17 years.	DEXA	0.99 (W) 0.99 (B)	DEXA
Pietrobelli *et al.*[168]	Males and females aged 7-14 years (n = 75).	DEXA	0.90	-
Phillips *et al.*[167]	Non-obese females aged 8-12 years (n = 196).	Deuterium dilution	0.95	Deuterium dilution
Rush *et al.*[182]	Males and females aged 5-14 years (n = 172).	Deuterium dilution	0.96	Deuterium dilution
Tyrrell *et al.*[228]	NZ European, NZ Maori, and Pacific Island males and females aged 5-11 years (n = 82).	DEXA	0.96	-

Consequences of Childhood Obesity

There can be little doubt that widespread surges in the prevalence of obesity will lead to extensive increases in obesity-related morbidity and mortality. From a public health perspective, it is essential that the specific health risks that accompany excessive levels of body fat are well understood and planned for. Although the health risks of obesity in children are less clear than in adults, there is growing evidence that the consequences of excessive body fat can manifest during childhood. Indeed, it has been reported that approximately 60% of overweight 5-10-year-old American children already have one cardiovascular risk factor, and 25% have two or more.[76] The majority of research in this area has focused on obese children in a clinical setting. These children generally exhibit more medical problems than the wider population, and as such, specific health risks may be overestimated. Nonetheless, the increasing prevalence of obesity-related morbidity observed in children and adolescents is a reminder that obesity can cause immediate problems in young people.

Obesity in pre-pubertal children is associated with insulin resistance, a major risk factor for type 2 diabetes.[31] This is reflected in the increasing prevalence of type 2, or ‘adult-onset’, diabetes in children and adolescents from USA, Japan, and among minority groups in Canada and Australia.[3] Insulin resistance has also been implicated in the development of hyperlipidaemia in obese adolescents,[13,202] a condition that increases the likelihood of cardiovascular disease (CVD). Additionally, Caprio *et al*.[31] found that insulin resistance can co-exist with hyperinsulinaemia in children within a relatively short period of excess adiposity.

Obese children are also more at-risk of developing hypertension and high LDL (low density lipoprotein) cholesterol than are children of normal weight. A recent longitudinal study of young Australians reported that overweight and obesity were predictors of higher systolic blood pressure in children aged nine years.[28] Interestingly, the relationship disappeared during early adolescence (12 years of age), and returned during late adolescence (15-18 years of age). The association of high total cholesterol and abnormal lipoprotein levels with childhood obesity is better established, particularly in boys.[75,78] Given the tendency for hypertension and hypercholesterolaemia to track into adulthood, these risks may have long term implications on CVD incidence.[75,127] It has been suggested that the increasing prevalence of Type 2 diabetes, hypertension, and high cholesterol in children will result in greater risk of vascular endothelial dysfunction.[83] This could potentially lead to increased rates of myocardial infarction among obese young adults in the near future, although there is evidence that vascular function may be restored by exercise and good nutrition.[253]

Another possible effect of overweight and obesity concerns the bone development of children. Given the positive effect of weight-bearing exercise on bone mass,[77] it is reasonable to assume that heavier, obese children will develop a higher bone mineral content (BMC) and will consequently be at a lower risk of fractures than lighter, non-obese children. While obese children do show a higher BMC and bone area than their non-obese peers, both variables become lower than in non-obese children when expressed relative to body weight.[89] This suggests that the additional bone development experienced by obese children is not enough to compensate for the heavier weight. Not surprisingly, the bone fracture rate for obese children in New Zealand is higher than that for non-obese children.[88,114]

Perhaps the most pervasive short-term consequences of childhood obesity are psychosocial. From kindergarten to secondary school, obese children face social stigmatisation, a trend that generally continues throughout adulthood. Children are more likely to express negative descriptors (e.g., stupid, lazy, less popular) towards images of overweight peers than for those depicting children of normal build,[97,211] and regard overweight classmates as the least preferable as friends.[203] Obese children are also vulnerable to bullying at school, which can (in turn) lead to adoption of bullying behaviour as a defence mechanism.[108] As obese children become adolescents, the consequences of discrimination and bullying on self efficacy are likely to intensify as their peers begin to assume a larger role than parents in the determination of self-image.[60] Indeed, the impairment of social development in overweight and obese children can be profound and long lasting.

Other short-term disorders associated with childhood obesity include sleep apnoea,[197] gallstones,[79] menstrual abnormalities,[115] lowered resistance to infection,[41] and asthma.[38] In addition, there is strong evidence that obesity tends to persists through adolescence and into adulthood. Table 1-3 summarises the most recent longitudinal studies that investigated the tracking of obesity in several countries, including New Zealand (studies published before 1990 were not included). The WHO has published extensive information on the negative health outcomes of obesity in adults, including the relative risk of each disorder for obese adults (Table 1-4).[255] It is clear that the increasing prevalence of childhood obesity will have serious long-term implications for public health.

Table 1-3. Longitudinal evidence for overweight and obesity tracking from childhood to adulthood.

Author(s) and Country	Sample Size	Measure	Summary of Findings
Burke *et al.*[28] Australia	600	BMI	Of those overweight or obese at age 9, 16% maintained the condition to young adulthood.
Casey *et al.*[33] USA	91	BMI	Strong association between childhood BMI and middle-age BMI in men but not women.
Clarke & Lauer[42] USA	2631	BMI	Depending on age and sex, 48-75% of children in the upper quintile of BMI were also in the upper quintile as adults.
Eriksson *et al.*[68] Finland	4515	BMI	Of those with a BMI greater than 90th percentile at age 5 and 9, 48% and 61% (respectively) reached a BMI > 30 in adulthood.
Gasser *et al.*[80] Switzerland	232	BMI Skinfolds	Predictive ability (r^2) of BMI during childhood for BMI during adulthood rose steeply with age, reaching 0.5 at age 9 for boys and at age 15 for girls. Similar trends for skinfolds, r^2 reaching 0.5 at age 10 for boys and at age 16 for girls.
Guo *et al.*[90] USA	338	BMI	Earlier BMI rebound by 1 year in females increases relative risk of adult overweight by 2.27 (no significant effect in males). During pubescence, a difference in 1 BMI unit corresponds to an increased relative risk of adult overweight by 2.0 in males and 3.6 in females.
Siervogel *et al.*[195] USA	496	BMI	Positive association observed between BMI at age 2 and 6 years and BMI at age 18 years
Williams[251] New Zealand	522	BMI	A BMI greater than the 75th percentile at age 7 was associated with a relative risk of 6.8 for overweight at age 21.

Table 1-4. Relative risk of obesity-related health complications in adults.[255]

Relative Risk > 3	Relative Risk ≈ 2-3	Relative Risk ≈ 1-2
Type 2 diabetes	Cardiovascular disease	Cancer (breast cancer in postmenopausal women, endometrial cancer, colon cancer)
Gallbladder disease	Hypertension	Reproductive hormone abnormalities
Dyslipidaemia	Osteoarthritis (knees)	Polycystic ovary syndrome
Insulin resistance	Hyperuricaemia and gout	Impaired fertility
Breathlessness		Low back pain
Sleep apnoea		Foetal defects

Physical Activity and Childhood Obesity

It is generally accepted that the susceptibility of a child to become obese is at least partially dependent on genetics. However, obesity is a complex disorder that stems from an interaction between genes and the environment. Put simply, obesity is the product of an energy imbalance in the body, with intake regularly exceeding expenditure.[255] Physical activity represents the key modifiable behaviour linked to the expenditure side of the thermodynamic equation, and is consequently a focus of many obesity prevention initiatives.

In 1996, the US Surgeon General released a landmark report that increased awareness of the benefits of physical activity for population health.[231] It was proposed that physical activity bouts can be split into smaller sessions without compromising health benefits, providing that the total duration is maintained. This resulted in a global shift from the promotion of strenuous sport or exercise to the encouragement of lifestyle changes that increase the accumulation of moderate-intensity physical activity. This development is of particular relevance for children, who are more likely to respond positively to programmes encouraging active play than to structured exercise regimens.[20]

The first national study to assess physical activity in children was the Life in New Zealand (LINZ) survey co-ordinated by the University of Otago during the late 1980s.[183] From this survey, it was estimated that 80% of New Zealand children aged 5-15 years participated in some form of regular physical activity. While the adult physical activity section of the LINZ survey correlated reasonably well with other subjective and objective measures,[100] children's physical activity information was gathered using a non-validated proxy-report (completed by a legal guardian). This tool is commonly used with young children to avoid the recall errors associated with self-report questionnaires.[45,119,184] Although practical and cost-effective, not all proxy-report questionnaires show acceptable validity in estimating physical activity.[158] Response accuracy is highly dependent on the type of information assessed, with reports on unchanging physical characteristics achieving greater precision than reports of highly subjective behaviours such as physical activity.[247] Furthermore, there is evidence that the characteristics of the proxy respondent can significantly affect recall of a child's health status.[172] Until validated, it is difficult to establish the accuracy of the physical activity data obtained using the LINZ proxy-report.

More recent information on the activity levels of New Zealand children was provided by three Sport and Physical Activity Surveys conducted between 1997 and 2001 by the Hillary Commission/Sport and Recreation New Zealand (SPARC).[201] Results from all three surveys indicated that 68% of New Zealanders aged 5-17 years undertook at least 2½ hours of sport or active leisure each week. Physical activity levels over the previous two weeks were estimated *via* a phone interview with a 'random adult' respondent in the same household. In addition to the conventional problems associated with subjective reports, it is likely that the accuracy of this particular system is dependent on the closeness of the relationship between the child and the respondent. However, the greatest shortcoming of the Sport and Physical Activity Surveys is the lack of data describing habitual physical activity in children.

In the 2002 CNS, physical activity patterns of 5-14-year-old children were evaluated using the Physical Activity Questionnaire for Older Children (PAQ-C) self-report protocol.[46] Although this study expanded on the Sport and Physical Activity Surveys by incorporating habitual activity, the appropriateness of the PAQ-C for assessing the activity of young children is questionable. Correlation between the PAQ-C and accelerometry in children aged 9-14 years is relatively weak ($r = 0.39$),[120] with no validation data available for younger children. Given the inherent inaccuracies associated with conducting self-report questionnaires in children,[45,119,184] the quality of the data is debatable. In any case, physical activity duration and intensity were not assessed, making it difficult to compare the CNS results with international standards.

It is clear that our understanding of physical activity in New Zealand children is currently inadequate. In recent years, the development of objective techniques to assess physical activity in young people has provided a better alternative to subjective questionnaires. Although direct observation is considered the 'gold standard' in children,[198] the considerable time and effort required to implement this technique precludes its use in population research. Furthermore, physical activity levels are usually recorded in 15 second epochs, which may be insufficient to capture the intermittent activity patterns common in children. The doubly labelled water method also offers a high level of validity and reliability,[198] but is impractical on a large scale due to the high cost and time-consuming preparation and analysis procedures. The objective tools frequently used to gather physical activity data in population studies are heart rate (HR) monitors, accelerometers, and pedometers.

HR monitors are often used in health research to provide real-time estimates of energy expenditure (EE) during children's natural activities. A transmitter belt worn around the chest detects electrical activity from the heart and sends an electromagnetic signal to the receiver attached to the wrist. These HR data can be stored for future analysis, and provide a good indication of both activity intensity and duration over the test period. Although an indirect estimate of physical activity, HR monitoring has been validated with oxygen consumption ($\dot{V}O_2$) in children during non-regulated play activity,[69] and with direct observation during high-level activity.[244] However, it has been suggested that the delayed reaction of HR in response to both the onset and cessation of movement may cause the sporadic activity patterns in children to be missed.[180]

Several different methods have been devised to estimate physical activity level from HR data. A conventional technique is to determine the amount of time each participant spends above a predetermined HR. One New Zealand study used a threshold of HR $\geq$ 140 bpm to represent MVPA, and found that only 32 out of 60 Christchurch children aged 10-13 years were achieving at least 30 min of MVPA on three out of four days.[29] This threshold was based on earlier research that reported a mean HR of 140 bpm during brisk walking from a sample of 98 children aged 5-16 years.[4] Although straightforward, this method suffers from a large degree of misclassification due to the substantial variance in fitness levels among participants. An alternative procedure is to measure the amount of time spent above a given percentage of resting heart rate (RHR). This technique controls for variation in fitness levels between participants, however the protocol used to define RHR has a considerable effect on estimates of childhood physical activity. Indeed, Logan *et al.*[136] demonstrated that time spent at a HR greater than 50% of RHR can vary by 16-65% depending on the interpretation of RHR. Until the definition of RHR is standardised, it is difficult to make valid comparisons between studies using this method.

Further problems with the HR method arise when activity decreases in intensity, and factors other than body movement exert a significant effect on HR (e.g., ambient temperature, hydration levels, emotional stress). In these instances, HR cannot be used to estimate activity status with a sufficient degree of accuracy. To overcome this problem, several studies have used regression equations individualising the HR-$\dot{V}O_2$ relationship for each child to establish a 'FLEX HR' point that falls between 'resting' and 'active' HR. For periods above the FLEX HR a linear HR-$\dot{V}O_2$ relationship is assumed; below the FLEX HR the predetermined resting metabolic rate is used. Estimates of children's EE using this technique have shown a relatively high degree of within-subject variability when compared with doubly labelled water[67,134] and indirect calorimetry,[17,67] with especially poor results in obese children.[142] One explanation for this variability is differences in the types of activity performed by the children during FLEX HR calibration and during the testing period. These differences may be largely unavoidable given that the simulation of a wide range of activities during calibration imposes an excessive burden on children.[135] Treuth *et al.*[214] found that predetermining two HR-$\dot{V}O_2$ relationships (one 'active' and one 'inactive') by using accelerometers to determine activity status could increase the accuracy of EE prediction from HR in a small sample of American children (N = 20). However, further testing is required for this method to be considered valid for use in large-scale research.

Of additional concern when using HR monitors is the 60 second sampling period required by most models to enable data collection to be sustained over several days. This is a potential source of error given that activities lasting less than 60 seconds may be missed. The most problematic issues, however, may be participant interference with the monitors, incorrect repositioning of transmitter belts by children and caregivers, and the use of transmitters that cannot be correctly fitted to children's chests. The recently released Polar Wearlink soft transmitter belts are designed to be highly flexible and may be better suited for use with children. Nevertheless, children tend to find chest belts uncomfortable to wear for extended periods,[181] and consequently participant non-compliance remains a concern in physical activity studies. The high cost of HR monitors that are able to store several days of data (approximately NZ$650 each) is another factor that may limit the appeal of this technique for population research.

Accelerometers are smaller and much less obtrusive than HR monitors, and have been used extensively in overseas studies to measure physical activity in children. Accelerometers use piezoelectric transducers and microprocessors to convert accelerations of the body into activity 'counts', with more vigorous movement resulting in a greater number of counts. Thus, both frequency and intensity of activity over a test period can be stored for later analysis, enabling participants who do not undertake the recommended amount of MVPA to be easily identified. It appears that at least five days of monitoring by accelerometry are required to obtain an acceptable estimate of physical activity in children.[218]

There is a range of accelerometers of varying reliability and validity. Of these, Computer Science and Applications (CSA/Actigraph), Tritrac-R3D, and Actiwatch accelerometers correspond well with higher standards of physical activity in children.[171,221,244] The CSA/Actigraph accelerometers are undoubtedly the most established in child health research. Recent models feature water-resistant casing, increasing the range of activities that can be monitored. Actiwatch accelerometers are also water-resistant, and have the added benefit of a digital integration data acquisition system that automatically determines intensity level. Initial comparisons with room respiration calorimetry and HR in children have shown promising results, with Actiwatch accelerometers performing slightly better than their CSA/Actigraph counterparts.[171] The increased accuracy of the Actiwatch accelerometer may be attributed to its omnidirectional measurement capability; CSA/Actigraph accelerometers are restricted to recording movement in the vertical plane.

Despite the benefits of using accelerometers in field studies of physical activity, there are several significant shortcomings. The first is cost: accelerometers are valued at approximately NZ$500 each, with some systems requiring the purchase of supplementary hardware and/or software. This factor alone may rule out the use of accelerometers in some large-scale surveys. The second drawback is that upper body movement, load carriage, or terrain changes may not be detected as accurately as other activities.[171] CSA/Actigraph accelerometers also appear to have difficulty distinguishing between different running velocities.[23] From a health promotion perspective, accelerometer counts have little meaning to the lay person, and the alternative method of expressing time spent at a given intensity of activity is dependent on a previously determined threshold that may vary among individuals. Furthermore, accelerometers appear to significantly overestimate the MVPA assessed by self-report questionnaire.[140] This is likely due to discrepancies between actual and perceived activity, and suggests that applying accelerometer-determined MVPA to the existing national guidelines (developed from self-report data) may be inappropriate. Finally, accelerometer data are organised into multiple 15-second epochs, each of which represents an average of the physical activity during that period. This could generate inaccuracies in younger subjects given their sporadic bursts of activity. For example, a child that runs for five seconds then sits down for ten seconds will be recorded as participating in 15 seconds of moderate activity, when no moderate activity actually occurred.

Pedometers are a cheaper alternative to accelerometers and as a result are widely used in field-based studies of physical activity. Similar in size to accelerometers, they can be purchased for as little as NZ$40 each and are worn on the waistline to record the number of steps taken each day. Of the various pedometer models, the Yamax Digiwalker series is the most popular for recording steps and distance in people of all ages.[49] In children, Eston *et al*.[69] found that steps recorded during play using the Digiwalker SW-200 were relatively consistent with $\dot{V}O_2$ and HR. A similar study by Kilanowski *et al*.[117] showed high correlations between the SW-200 and both the Tritrac-R3D accelerometer and direct observation during children's recreational physical activity. More recently, the New Lifestyles NL-2000 pedometer was released featuring an internal clock that can categorise data according to the day of the week for up to seven days, thereby removing the need for researchers to collect data each day of the test period. Although yet to be validated in children, the NL-2000 appears to be one of the most accurate pedometers for measuring steps in adults.[49]

The major disadvantage of utilising pedometers in physical activity research is that they are unable to provide an indication of the timing, frequency, type, or intensity of activity. Scruggs *et al*.[191] overcame the latter during a 30-minute physical education lesson by comparing steps.min^{-1} with time spent in MVPA (assessed *via* direct observation). This enabled the derivation of steps.min^{-1} benchmarks that corresponded to a specific percentage of class-time in MVPA. However, applying this methodology to free-living children over an entire day would be costly, time-consuming, and ultimately impractical. A further drawback of pedometers is the reduction in sensitivity during low-intensity activity, possibly due to the inability to detect side-to-side and upper body movement.[69] This may result in an underestimation of physical activity, especially in sedentary children who spend a higher proportion of time in a low-activity state. It has also been suggested that excessive body fat around the waist in overweight individuals may tilt pedometers to an angle at which precision is reduced. Although there is evidence both for[148,194] and against[205] this hypothesis in adults, the association between body size and pedometer validity in children is unknown. In spite of these shortcomings, there are obvious advantages to quantifying physical activity by pedometry. Increasing total number of daily steps is a relatively straightforward concept to understand, and the active feedback provided by the pedometer can serve as an effective motivating factor. Furthermore, the implementation of steps.day^{-1} as a universal physical activity 'currency' facilitates straightforward comparisons between children, adolescents, and adults from various populations.

While the promotion of physical activity in children is widely regarded as a fundamental preventative step in controlling the worldwide obesity 'epidemic', research into the role of physical activity in the development of childhood obesity has been inconsistent (Table 1-5). Sunnegardh *et al.*[204] reported no correlation between physical activity status and body fat percentage as assessed by skinfold testing. One large study of over 10,000 children and adolescents found a significant relationship between BMI and physical activity in girls, but not boys.[15] Another survey found that physical activity was a significant predictor of excess BMI gain over a two-year period in both sexes.[160] It should be noted that physical activity data from these three studies were obtained by a self-report questionnaire. Maffeis *et al.*[143] used a parental questionnaire to avoid child recall error, and found that physical activity level did not affect the change in relative BMI over a four-year period. However, the proxy report used in this study was not previously validated and consequently the relevance of the results is questionable. Objective estimates of physical activity consistently demonstrate inverse associations with both BMI[154,217,220] and body fatness[110,150,154,181] in children of all ages (Table 1-5). In fact, a negative relationship between body fatness and objectively-determined activity can be observed in children as young as 12 months of age.[133] This suggests that, given valid and reliable estimates of activity, there is a clear link between obesity and physical activity in children.

Given the prevailing evidence that physical activity levels and body fatness in children are related, the question must be asked: “How much physical activity is required to prevent obesity?” Over the past decade, several organisations have issued guidelines to inform the public of the minimum physical activity requirements for maintaining good health. The US Surgeon General recommended that people of all ages accumulate at least 30 minutes of moderate to vigorous physical activity each day to achieve health benefits.[231] The Health Education Authority (UK) extended these guidelines to 60 min.day^{-1} for young people in response to the widespread increases in the prevalence of childhood and adolescent obesity.[93] Although this recommendation was endorsed by both the UK Department of Health[56] and the International Association for the Study of Obesity,[187] the specific amount of physical activity required to circumvent overweight and obesity in children remains uncertain.

As an alternative to guidelines based on the intensity and duration of physical activity, daily step count targets have been proposed for achieving health benefits.[222] In a recent study, Tudor-Locke *et al.*[224] proposed that 12,000 steps.day^{-1} for girls and 15,000 steps.day^{-1} for boys are appropriate goals for the maintenance of a healthy BMI. Although BMI is a less than ideal estimate of body fatness, the use of steps.day^{-1} as a physical activity ‘currency’ has several potential benefits. First, increasing the total number of steps each day is a relatively straightforward concept to understand, even for children. Second, sedentary and/or obese children can increase their daily step count without the excessive stress or embarrassment associated with participation in sports or exercise sessions. Pedometer-based interventions have already proven effective for increasing physical activity in adults[47,226] and adolescent girls.[190] Third, pedometers are relatively cheap (NZ$40); ideal for use in large-scale population research. Finally, the number of accumulated steps.day^{-1} can be directly compared with international data.

It is clear that the implementation of objective measurement techniques in a large-scale study of physical activity in New Zealand children is overdue. Pedometers may be the best option in this regard, given their low cost and applicability to recent trends in health promotion. Daily step count information would provide valuable insight into the physical activity behaviours of young New Zealanders; essential for determining the best method of counteracting the rising tide of overweight and obesity.

Table 1-5. Summary of studies investigating the associations between physical activity and body composition in children.

Reference	Sample	Study Design	Physical Activity Measure	Body Composition Measure	Summary of Findings
Berkey *et al.*[15]	4620 boys, 6149 girls 9-14 years	Longitudinal (one year)	Self-report	BMI	Increase in BMI over one year was larger in girls (but not boys) who were less active.
Elgar *et al.*[66]	177 boys, 212 girls 11-14 years	Longitudinal (four years)	Self-report	BMI	Increase in BMI over four years was larger in boys and girls who were less active.
Janz *et al.*[110]	217 boys, 250 girls 4-6 years	Cross-sectional	Accelerometers	DEXA	Inverse correlation detected between %BF and activity in boys and girls.
Li *et al.*[133]	15 boys, 15 girls 6-12 months	Longitudinal (six months)	Direct observation	DEXA	Activity at 12 months was inversely related to %BF at 6-9 months.
Maffeis *et al.*[143]	112 boys and girls 8-12 years	Longitudinal (four years)	Proxy report	BMI	No significant association between activity and the increase in BMI over four years.
Mikami *et al.*[150]	30 boys 11-12 years	Cross-sectional	HR monitors Pedometers	Skinfolds	Obese boys achieved fewer daily steps than non-obese boys. No difference in HR.
Moore *et al.*[154]	63 boys, 40 girls 4-11 years	Longitudinal (eight years)	Accelerometers	BMI Skinfolds	Increase in BMI and skinfolds over eight years was larger in boys and girls who were less active.
O'Loughlin *et al.*[160]	319 boys, 314 girls 9-12 years	Longitudinal (two years)	Self-report	BMI	Increase in BMI over two years was larger in boys and girls who were less active.
Rowlands *et al.*[181]	17 boys, 17 girls 8-10 years	Cross-sectional	HR Monitors Accelerometers Pedometers	Skinfolds	Inverse correlation detected between %BF and accelerometer and pedometer counts in boys and girls.
Sunnegardh *et al.*[204]	682 boys and girls 8-13 years	Cross-sectional	Self-report	Skinfolds	No significant correlations between %BF and activity.
Trost *et al.*[217]	103 boys, 110 girls 10-12 years	Cross-sectional	Accelerometers	BMI	Obese boys and girls achieved less activity than non-obese children.
Trost *et al.*[220]	118 boys, 127 girls 3-5 years	Cross-sectional	Direct observation Accelerometers	BMI	Overweight boys achieved less activity than non-overweight boys. No difference in girls.
Vincent *et al.*[237]	959 boys, 995 girls 6-12 years	Cross-sectional	Pedometers	BMI	Few significant inverse relationships between BMI and activity.

Dietary Factors Associated with Childhood Obesity

Despite the important benefits of physical activity for modulating body fat accumulation through increased energy expenditure, it represents only one side of the thermodynamic equation that determines the body's energy balance. Excessive energy intake through regular consumption of foods high in energy is also a key determinant for the development of overweight and obesity. Data from the WHO multinational monitoring project (MONICA) present a strong case for the role of energy-dense food and greater energy supply in widespread increases in BMI, with secular trends in total energy supply per capita explaining 51% of the differences in BMI trends between populations.[196] By contrast, there is evidence that daily caloric intake and average fat intake of US[95] and UK[170] adults showed little variation from the late 1970s to the early 1990s despite substantial increases in the prevalence of overweight and obesity during this period. Similar trends have been reported in paediatric populations: data from the NHANES III showed little change in the mean energy intake for children aged 2-19 years between 1971 and 1994 (with the exception of adolescent girls).[216] Likewise, the Dortmund Nutritional Anthropometric Longitudinally Designed (DONALD) Study found that the differing BMI profiles of children and adolescents during development could not be explained by differences in dietary patterns.[2] At first glance, these findings suggest that energy intake has had little or no influence on the rise in obesity prevalence. However, it is noteworthy that overweight individuals tend to under-report energy intake, potentially distorting surveys of nutritional status.[7,24,70,104,169] It is therefore possible that the absence of self-reported increases in energy intake over time may reflect greater levels of overweight and obesity in these populations and greater error in self-reported caloric intake.

As an alternative to total energy input, examination of specific 'unhealthy' eating habits associated with excessive energy intake and body fatness can provide valuable information. For example, Gillis *et al*.[85] found that obese children consumed significantly more food away from home than non-obese children. This observation was supported by Thompson *et al*.,[210] who demonstrated a positive correlation between the frequency of fast food consumption and longitudinal changes in BMI in girls, and by Veugelers *et al*.,[235] who reported an increased risk of overweight in children that use school food services. Although these studies do not necessarily imply causation, regular consumption of food away from home appears to be an important dietary risk factor for the development of obesity in children. Indeed, most of the options offered by fast foods outlets and school food services contain high levels of fat.[22,32]

Frequent consumption of products high in sugar content has also been linked to rising levels of body fatness. Among children and adolescents, carbonated sugary drinks (or 'soft drinks') are thought to be one of the biggest contributors to excessive sugar intake. Data from the USA indicate that mean soft drink consumption doubled in girls and tripled in boys between 1967 and 1996.[34] This is a concern given the positive correlation between soft drink consumption and body size in children observed in a number of studies.[14,82,85,139] An investigation of the relationships between BMI, triceps skinfolds, and intake of sugar-sweetened drinks over a two-year period by Ludwig *et al.*[139] concluded that children were 60% more likely to be obese with each additional can or glass of soft drink consumed each day. Similar results were observed by Gillis and Bar-Or,[85] who noted that obese children averaged two more sugar-sweetened drinks each week than non-obese children. One explanation for these findings is that, as with adults, the energy gained from consuming sugary drinks is not compensated for by a reduction in the ingestion of energy from other sources.[54] In fact, children who consume more than 265 ml of soft drinks each day increase their average daily energy intake by 835 kJ, which represents an energy increase of approximately 10% each day.[91]

There is also compelling evidence that skipping breakfast increases the risk of overweight and obesity in young people.[21,66,159,174,234] However, the mechanisms underlying this particular association are less clear than for fast food or sugary drink consumption. It is possible that skipping breakfast is a symptom of obesity rather than a cause, resulting from an increased prevalence of dieting practices.[21,27] This hypothesis was supported by findings that children who skip breakfast consume fewer daily calories that those who regularly eat breakfast.[16] In any case, the applicability of international data to the New Zealand population is not known. Elucidation of the key dietary risk factors contributing to excessive fat accretion in young New Zealanders would be beneficial for guiding the development of national obesity interventions.

Thesis Rationale

There is substantial evidence that obesity during childhood is associated with serious health complications; obese children have an elevated risk of insulin resistance, hypertension, and high cholesterol, and are likely to face social stigmatism from an early age. Moreover, the tendency for obesity to track into adulthood raises the prospect of other chronic disorders, such as cardiovascular disease, type 2 diabetes, and cancers. There can be little doubt that widespread increases in the prevalence of childhood overweight and obesity will have major public health implications for many countries. National estimates of BMI-determined obesity in children suggest that New Zealand is on a par with Australia, USA, and the UK. However, the relation between these BMI estimates and actual body fat levels is not yet known.

An understanding of the key risk factors contributing to fat accretion in children is essential for evidence-based strategic planning and lifestyle interventions. While the CNS identified several factors responsible for a high BMI in New Zealand children,[232] assessing the determinants of elevated body fatness is more relevant with regard to health risk. The development of BIA as a valid and reliable procedure for assessing body composition in paediatric populations has enabled researchers to evaluate body fat levels without the difficulties associated with skinfold testing. Thus, a key objective of this thesis was to provide accurate body fat data by utilising BIA in a large sample of young New Zealanders. This enabled the demographic and lifestyle-related correlates of excess adiposity in New Zealand children to be determined for the first time.

As with body composition, there is also a dearth of valid data describing physical activity in New Zealand children. Previous surveys have relied on subjective questionnaires, the majority of which have not been validated with more direct measures. Given the high priority placed on physical activity in recent government policy,[151] it is important that we have a clear picture of the activity patterns in young people. This leads to another novel aspect of this thesis: the evaluation of physical activity in New Zealand children using objective measurement techniques. Pedometers were selected to fulfil this role due to their portability, cost-effectiveness, and increasing popularity in health promotion. The use of a recently released MDM pedometer (NL-2000) enabled weekday steps to be contrasted with mean step counts for the weekends. An additional benefit of using pedometers was the potential to compare daily step counts with body fat levels, facilitating the first step count recommendations for children based on reducing the risk of excess adiposity.

Despite the advantages of using pedometry in a paediatric sample, there were several potential issues to resolve. First, the validity of the NL-2000 pedometer had not been established in children, and the effect of children's body size on pedometer performance was not known. Second, the reactivity of children to wearing pedometers had only been assessed using pedometers that require researchers to manually record step counts each morning. This high level of participant/researcher interaction may have masked reactivity by triggering an abnormally high activity level for the duration of the test period. The development of MDM pedometers has enabled children's reactivity to be determined without excessive researcher influence. Consequently, the preparation procedure that minimises reactivity can also be determined. Finally, the impact of variable weather patterns on the activity behaviour of young people has yet to be investigated. If the weather plays a large part in children's physical activity choices, then any comparisons of mean step counts between independent variables (e.g., sex, ethnicity, body size) may be confounded by differences in environmental conditions. Obtaining comprehensive weather data during the main study of this thesis enabled associations between weather and activity to be examined.

Clearly, the current obesity trends in New Zealand children warrant urgent attention from researchers and policy-makers alike. The overall aim of this thesis was to provide a detailed description of the key determinants of excess fatness in New Zealand children, with a particular focus on physical activity. It is envisaged that this information will assist in the development of evidence-based strategies for preventing obesity in young New Zealanders.

Thesis Organisation

This thesis consists of eight interrelated chapters, the majority of which have been submitted as scientific papers. Figure 1-3 summarises the overall organisation of the thesis. An introduction of the literature and a rationale for the thesis is present in Chapter 1. The data for Chapters 2 and 3 were obtained from two preliminary studies. These findings were used to inform the main study in this thesis: a cross-sectional survey of body composition, physical activity, and selected lifestyle behaviours in 1229 primary-aged children. Chapters 4-7 detail distinct aspects of the latter study, concluding with a general discussion in Chapter 8. It should be noted that Chapter 6 was written in the format of a Short Communication (Appendix A), and is therefore shorter in length than the other chapters.

As Chapters 2-7 are comprised of six scientific papers, there may be some duplication in the introduction and methods sections. However, each chapter should be thought of as essentially independent, with its own focused literature review and discussion. As the publication dates for each chapter vary, the published papers arising from the later chapters may be cited in preceding chapters. The general discussion in Chapter 8 provides a summary of the main points in each chapter while noting the limitations of the three research studies.

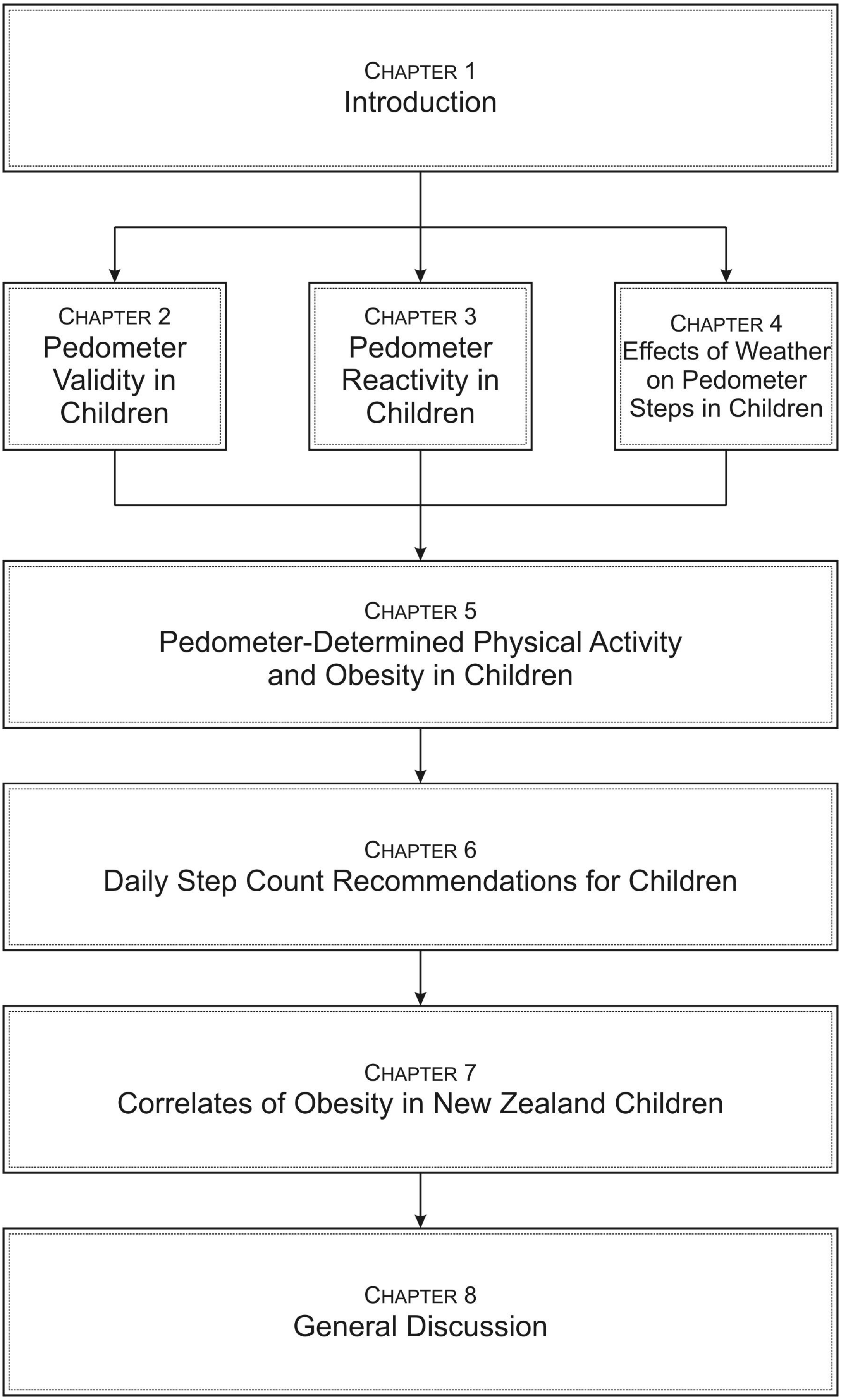

Figure 1-3. Overview of thesis organisation.

CHAPTER 2

PEDOMETER VALIDITY IN CHILDREN

Preface

The main study in this thesis utilised pedometers to collect objective measurements of physical activity in a large sample of New Zealand children. The recently released NL-2000 pedometer was the preferred option given its ability to automatically record step counts for each day. The multiday memory function removes the need for researchers to manually record step counts on each morning of the monitoring period, greatly reducing the time and cost associated with large-scale pedometry studies. However, prior to this thesis, the NL-2000 had not been validated as a measure of ambulatory activity in paediatric subjects. The preliminary study described in this chapter was designed to test the overall performance of the NL-2000 for detecting steps in children with the intention of informing the main descriptive study in this thesis. The paper resulting from this chapter was accepted for publication in *Research Quarterly for Exercise in Sport* (January, 2007) and is currently in press.

Abstract

Objective: The objective of this study was to investigate the effects of age group, walking speed, and body composition on the accuracy of pedometer-determined step counts in children.

Methods: Eighty-five participants (43 boys, 42 girls) aged 5-7 and 9-11 years walked on a treadmill for two-minute bouts at speeds of 42, 66, and 90 $m.min^{-1}$ while wearing a spring-levered (Yamax SW-200) and a piezoelectric (New Lifestyles NL-2000) pedometer. The number of steps taken during each bout was also recorded using a hand counter. Body mass index (BMI) was calculated from height and weight, and %BF was determined using hand-to-foot bioelectrical impedance analysis. The tilt angle of the pedometer was assessed using a magnetic protractor.

Results: Both pedometers performed well at 66 and 90 $m.min^{-1}$, but undercounted steps by approximately 20% at 42 $m.min^{-1}$. Although age group, BMI, waist circumference, or %BF did not affect pedometer accuracy, children with large pedometer tilt angles

(≥ 10º) showed significantly greater percent bias than those with small tilt angles (< 10º). We suggest that the style of waistband on the child's clothing is a more important determinant of tilt angle and thus pedometer accuracy than body composition. Our results also indicate that the NL-2000 pedometer provides similar accuracy and better precision than the SW-200 pedometer, especially in children with large tilt angles.

Conclusions: We conclude that fastening pedometers to a firm elastic belt may improve stability and reduce undercounting in young people. However, the low accuracy of pedometers for measuring children's steps at slow walking speeds remains a concern.

Introduction

Widespread increases in childhood overweight and obesity have triggered an upsurge in the promotion of physical activity in young people. In this regard, the use of pedometers to monitor daily step counts offers several advantages over traditional strategies based on time spent in moderate to vigorous physical activity. Increasing the number of steps accumulated each day is a straightforward concept to understand, and is non-threatening for children of all body sizes and physical abilities. For researchers, pedometers provide an objective and cost-effective measure of children's activity that can be easily compared across study populations and time periods. In recent years, a growing number of studies have utilised pedometers to provide cross-sectional physical activity data[62,237] and to evaluate activity interventions in children.[164,190]

While unable to measure the intensity, frequency, or duration of activity, pedometers provide estimates of overall activity that correlate well with accelerometers,[117] heart rate monitors,[69] and observational techniques.[191] However, only two studies have investigated the validity of pedometers for measuring children's steps in a controlled setting. Ramírez-Marrero *et al.*[173] compared the step counts recorded by a Yamax Digiwalker SW-200 pedometer with observed steps during two minutes of treadmill walking. Their results indicate that the SW-200 performs accurately at speeds of 70 and 90 $m.min^{-1}$, but underestimates steps by an average of 12.9% at a speed of 58 $m.min^{-1}$. Beets *et al.*[12] conducted a similar study examining the accuracy of the SW-200 pedometer along with three other models: the Walk4Life 2505, the Sun TrekLINQ, and the Yamax Digiwalker SW-701. When compared with observed steps, the mean percent bias for all four pedometers was significant at slow walking speeds of 40 and 54 $m.min^{-1}$.

The accuracy of pedometers at different walking speeds may also depend on the age of the child. At present, there are no data describing differences in pedometer error between age groups. Biokinetic research suggests that children aged 5-6 years adopt walking features distinct from those aged 7-12 years.[112] Young children showed greater variability in intra-limb coordination and more difficulty maintaining symmetry when compared with older children, who demonstrated a mature walking form similar to that observed in adults. Not surprisingly, young children also produce less ground reaction force (GRF) than older children due to their lighter weight.[207] It is possible that these factors may contribute to age-specific variation in the measurement bias associated with pedometers.

Another layer of complexity is added when the potential effects of body size on pedometer accuracy are considered. It has been proposed that excess abdominal adiposity in some individuals may reduce the ability of pedometers to detect steps by obstructing correct placement on the waistline or by dampening vertical accelerations of the body.[225] In adults, a positive association between body mass index (BMI) and pedometer bias was observed by Melanson *et al.*[148] and Shepherd *et al.*[194], but not by Swartz *et al.*[205] More recently, Crouter *et al.*[48] concluded that the effects of both BMI and waist circumference (WC) were less important than tilt angle with regard to the measurement error of SW-200 pedometers in obese adults. The latter authors hypothesised that increased friction on the spring-suspended lever arm due to tilt away from the vertical plane may lead to the underestimation of steps. Indeed, the authors noted that accuracy of a pedometer that operates via a piezoelectric strain gauge (New Lifestyles NL-2000) was not affected by tilt angle. To date, no studies have investigated the associations among pedometer accuracy, body size, and tilt angle in young people for spring-levered or piezoelectric pedometers.

In addition to a piezoelectric mechanism, the NL-2000 offers an advantage over conventional pedometers (such as the SW-200) with its multiday memory (MDM) function that automatically categorises data according to the day of the week. This removes the need for researchers to visit participants each morning to record the steps for the previous day, enabling step count data for both weekdays and weekends to be collected without difficulty.[62] Despite these technical advancements, the ability of the NL-2000 pedometer to estimate steps in children has yet to be assessed.

It is clear that there are several potential sources of measurement error in pedometer-determined physical activity yet to be explored in a paediatric sample. The purpose of this study was to determine the effects of children's walking speed, age, and body composition on pedometer accuracy and precision. A secondary objective was to compare the performance of a spring-levered (SW-200) and a piezoelectric pedometer (NL-2000) for recording steps in children.

Methods

Participants

A total of 85 children (43 boys, 42 girls) aged 5-11 years were selected from a primary (elementary) school in Auckland, New Zealand. The sample was composed of two distinct age groups: those from Years 1 and 2 (5-7 years; 42.4%) and those from Years 5 and 6 (9-11 years; 57.6%). The ethnic composition of the sample was 43.5% Caucasian, 32.9% Asian, 12.9% Polynesian, and 10.6% from other ethnicities. Written informed consent was provided by each participant and his or her legal guardian. Ethical approval for this study was obtained from the institutional ethics committee (Appendix B).

Body Composition Measurements

The height and mass of each participant was measured using a portable stadiometer (Design No. 1013522, Surgical and Medical Products, Seven Hills, Australia) and a digital scale (Model Seca 770, Seca, Hamburg, Germany). BMI was calculated as mass (kg) divided by squared height (m^2). WC measurements were made at the highest point of the iliac crest at minimal respiration. Resistance (R) measurements were obtained at 50 kHz using a bioimpedance analyser (Model BIM4, Impedimed, Capalaba, Australia) with a tetrapolar arrangement of self-adhesive electrodes (Red Dot 2330, 3M Healthcare, St Paul, MN, USA). Participants were asked to empty their bladder before lying supine with their arms and legs abducted. Testing continued until measurements of R were within 1 ohm of each other. A prediction equation previously validated in New Zealand children[182] was used to obtain estimates of fat-free mass and fat mass from height, weight, and R values. Percentage body fat (%BF) was then calculated as the ratio of fat mass to weight multiplied by 100.

Pedometer and Treadmill Procedures

The accuracy of the Yamax Digiwalker SW-200 (Yamax Corp., Tokyo, Japan) and New Lifestyles NL-2000 pedometers (New Lifestyles Inc., Lee's Summit, MO) were assessed in this study. To ensure representative results, five units of each model were tested (ten in total). Prior to use, all pedometers were checked for faults using five repetitions of the 100-step walking test described by Vincent and Sidman[238]. This process was repeated once during testing and once following the completion of data collection. Absolute error was no more than two steps (2%) for each of the ten pedometers tested.

Each participant was asked to walk normally on a treadmill (Accumil-P, Pacer Fitness Systems Inc., Irving, TX) for three bouts of two minutes. The treadmill speed was set to 42 $m.min^{-1}$ for the first bout, 66 $m.min^{-1}$ for the second bout, and 90 $m.min^{-1}$ for the third bout. These speeds were selected to simulate slow, moderate, and fast walking in children. The treadmill was initially calibrated by measuring the belt length and the time taken to complete 30 revolutions at the lowest and highest testing speeds. The gradient was set to 1% to replicate normal walking conditions.[113] After becoming familiar with walking on the treadmill, participants placed their feet on either side of the belt while a SW-200 and a NL-2000 pedometer were fastened to the waistband of their clothing at the anterior midline of the right and left thigh. The placement of the pedometers was randomised for each participant so that both models were tested on right and left sides. At the completion of each bout, participants were instructed to straddle the treadmill while pedometer steps were noted and reset to zero. The number of steps accumulated in each bout was also recorded by a researcher using a hand counter. Pedometer tilt angles were measured pre- and post-test using a magnetic protractor (Empire Level Manufacturing Corp., Mukwonago, WI) while standing normally next to the treadmill, with the average of the two measurements used in subsequent analyses. A positive angle indicated that the top of the pedometer tilted away from the body, whereas a negative angle denoted a tilt towards the body.

Statistical Analyses

All data were analysed using SPSS version 14.0 for Windows (SPSS Inc., Chicago, IL) and a P value less than 0.05 to indicate statistical significance. Descriptive statistics were generated for age, height, weight, BMI, WC, and %BF, and were expressed as mean ± SD. Differences among sex and age groups were examined using independent samples *t*-tests. Bias (pedometer steps – observed steps) was converted to a percentage of observed steps to assess the relative under- or overestimation of pedometer steps for each model. A negative percent bias indicates undercounting, while a positive percent bias indicates overcounting. The 95% limits of agreement and loss of precision statistics were also calculated to provide an indication of reliability. The loss of precision, or the variance of prediction error divided by the variance of the criterion value, measures the theoretical increase in sample size required to offset the prediction error.[72] The consistency of percent bias at the extremes of the observed step count distribution was investigated using correlation analysis. For example, a significant correlation between the observed steps and the percent bias would indicate that the relative error associated with pedometers varies with the number of steps taken.

To identify the variables associated with percent bias for each pedometer type, sex (male and female), age group (Years 1-2 and Years 5-6), and speed (42, 66, and 90 $m.min^{-1}$) were entered into a 2 × 2 × 3 factorial repeated measures ANOVA (Sex by Age Group by Speed). BMI, WC, %BF, and pedometer tilt angle were added into the model separately as covariates. After dividing participants into small tilt angle (< 10°) and large tilt angle (≥ 10°) groups, modified Bland-Altman plots were generated for both models to demonstrate the effects of pedometer tilt on the mean percent bias and 95% prediction interval. The observed step counts were used on the x-axes (rather than the mean of the observed and pedometer step count) given the negligible error associated with this measure.

Results

Table 2-1 shows the physical characteristics of the study sample. In general, children aged 9-11 years were taller and heavier, with a larger BMI, WC, and %BF ($P < 0.01$). Two exceptions were the 1.4 $kg.m^{-2}$ difference in BMI ($P = 0.190$) and the 2.5% difference in %BF ($P = 0.223$) between younger and older girls. The only significant difference between sexes was a 4.3% higher %BF in 5-7-year-old girls when compared with boys of the same age ($P = 0.016$). Based on international age- and sex-specific BMI cut-off points,[44] 19.0% (boys) and 20.0% (girls) of participants were classified as overweight, while a further 7.1% and 10.0% were obese.

Table 2-1. Participant characteristics for pedometer validity study sample.

	5-7 Years		9-11 Years	
	M (*N* = 17)	**F (*N* =19)**	**M (*N* = 26)**	**F (*N* = 23)**
Age (years)	6.0 ± 0.5	6.2 ± 0.7	9.9 ± 0.6	10.1 ± 0.7
Height (cm)	116.8 ± 8.1	116.1 ± 6.3	141.0 ± 7.5	140.7 ± 6.0
Weight (kg)	22.4 ± 4.4	23.6 ± 7.5	38.2 ± 9.1	36.9 ± 6.2
Body Mass Index ($kg.m^{-2}$)	16.3 ± 1.5	17.2 ± 3.6	19.1 ± 3.5	18.6 ± 2.8
Waist Circumference (cm)	53.5 ± 4.7	53.3 ± 7.5	63.7 ± 9.0	62.1 ± 6.8
Body Fat (%)	16.5 ± 3.4	20.8 ± 5.8	22.1 ± 6.9	23.3 ± 6.1

Data are presented as mean ± SD. M, male; F, female.

The relationships between the observed and measured step counts for the SW-200 and NL-2000 pedometers are presented in Figure 2-1. The overall performance of the two pedometers was similar, with both models underestimating steps during slow and moderate walking (42 and 66 $m.min^{-1}$). Slow walking, in particular, resulted in high percent bias and 95% limits of agreement (Table 2-2). The mean percent biases produced during moderate walking were smaller; however the limits of agreement remained relatively high. Although only the SW-200 pedometer achieved a percent bias statistically equivalent to zero during fast walking, both models performed adequately at this speed. The positive correlations between observed steps and percent bias at slow and moderate walking speeds indicate that the underestimation was greatest for participants that accumulated the fewest number of steps during the measurement periods. The loss of precision was relatively high at slow and moderate speeds, with smaller values for the NL-2000 than the SW-200 pedometer. There was no significant difference in percent bias between the SW-200 (-8.6 ± 14.7%) and the NL-2000 (-8.5 ± 13.3%) pedometer when data from all three speeds were combined ($P = 0.855$). Furthermore, a positive correlation in mean percent bias between pedometers was detected ($r = 0.745$, $P < 0.001$), suggesting that children tend to have similar bias levels for each model.

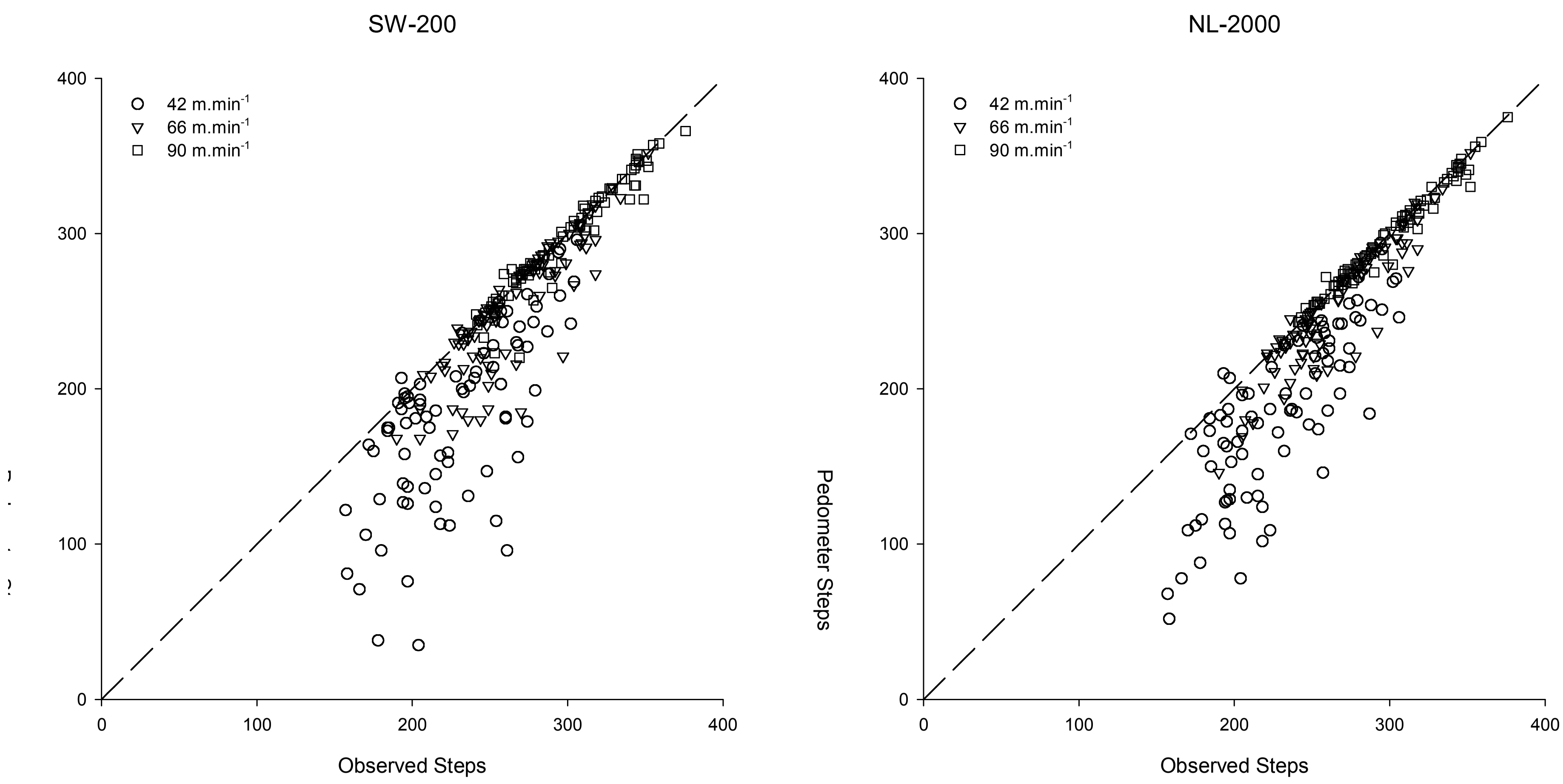

Figure 2-1. Correlation between observed and measured steps using the SW-200 and NL-2000 pedometers in children walking at 42, 66, and 90 $m.min^{-1}$.
Dashed line represents perfect correlation.

Table 2-2. Validity of SW-200 and NL-2000 pedometers for measuring steps at 42, 66, and 90 $m.min^{-1}$ in children.

Speed	Mean difference in steps[a]	$r_{y,y'}$[b]	Mean percent bias (%)[c]	P[d]	Proportion of over- and undercounting (%)	$r_{y,\%bias}$[e]	95% limits of agreement (%)[f]	Loss of precision (%)[g]
SW-200								
42 $m.min^{-1}$	-44.6 ± 40.9[h]	0.708	-20.1	0.000	3.5/3.5/92.9[i]	0.213 (P = 0.051)	-57.7, 17.5	108.8
66 $m.min^{-1}$	-13.2 ± 20.7	0.875	-5.2	0.000	27.1/5.9/67.1	0.181 (P = 0.097)	-21.1, 10.7	35.0
90 $m.min^{-1}$	-2.1 ± 9.4	0.964	-0.7	0.061	49.4/11.8/38.8	-0.084 (P = 0.445)	-7.3, 5.9	7.1
NL-2000								
42 $m.min^{-1}$	-45.0 ± 32.2	0.813	-20.6	0.000	2.4/1.2/96.5	0.362 (P = 0.001)	-52.5, 11.3	67.4
66 $m.min^{-1}$	-11.4 ± 14.7	0.935	-4.5	0.000	11.8/11.8/76.5	0.298 (P = 0.006)	-16.3, 7.3	17.5
90 $m.min^{-1}$	-1.7 ± 5.8	0.987	-0.5	0.019	40.0/10.6/49.4	-0.270 (P = 0.013)	-4.2, 3.2	2.7

[a]Difference in steps = pedometer steps - observed steps (mean ± SD).
[b]Correlation coefficient between observed steps and pedometer steps.
[c]Percent bias = ([pedometer steps - observed steps]/observed steps) × 100.
[d]Probability that mean percent bias = 0.
[e]Correlation coefficient between the observed steps and the percent bias.
[f]95% limits of agreement = mean percent bias ± 1.96 × percent bias SD.
[g]Loss of precision = ([variance of pedometer steps - observed steps]/variance of observed steps) × 100.
[h]Mean ± SD.
[l]Overcounting/Exact counting/Undercounting.

To determine the factors associated with the percent bias at each of the three walking speeds, a factorial repeated measures ANOVA (Sex by Age Group by Speed) was conducted for each pedometer type. Associations between percent bias and walking speeds were observed (SW-200, $F = 91.915$, $P < 0.001$; NL-2000, $F = 123.770$, $P < 0.001$), with significant interactions between speed and age group for the NL-2000 pedometer ($F = 8.653$, $P < 0.001$), and between speed and sex for both pedometer models (SW-200, $F = 3.688$, $P = 0.027$; NL-2000, $F = 4.542$, $P = 0.012$). In other words, our data indicate that the reduction in mean percent bias with increasing speed levels varies with sex (and age group in the NL-2000). Overall, boys averaged 5.4% (SW-200, $F = 7.317$, $P = 0.008$) and 3.4% (NL-2000, $F = 5.256$, $P = 0.024$) less bias than girls. Sex-specific differences in percent bias were significant for all walking speeds in the SW-200 (slow, 9.1%, $t = 2.235$, $P = 0.028$; moderate, 4.4%, $t = 2.580$, $P = 0.012$; fast, 1.9%, $t = 2.675$, $P = 0.010$) and at slow walking speeds only in the NL-2000 (7.1%, $t = 2.050$, $P = 0.044$; Figure 2-2). Although mean percent bias was 2.8% (SW-200) and 4.1% (NL-2000) higher in older children than in younger children, the difference was significant for the NL-2000 only ($F = 7.803$, $P = 0.007$). Age-specific differences in NL-2000 bias were significant during slow (9.6%, $t = 3.034$, $P = 0.003$) and moderate (2.7%, $t = 2.184$, $P = 0.032$) walking, but not during fast (0.5%, $t = -1.249$, $P = 0.215$) walking (Figure 2-3).

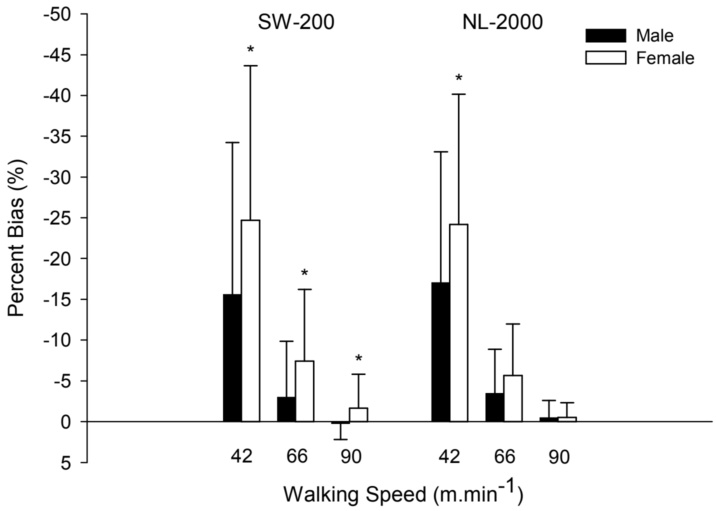

Figure 2-2. Percent bias of SW-200 and NL-2000 pedometers for boys and girls walking at 42, 66, and 90 $m.min^{-1}$.

Data are presented as mean ± SD.
*Significant difference from male ($P < 0.05$).

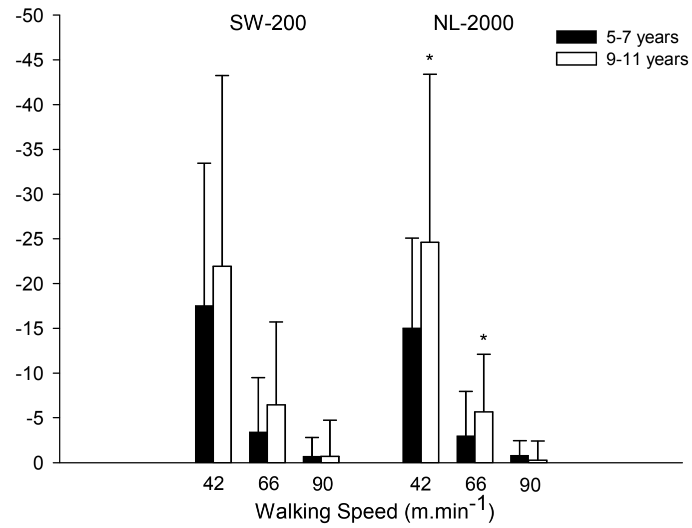

Figure 2-3. Percent bias of SW-200 and NL-2000 pedometers for children aged 5-7 and 9-11 years walking at 42, 66, and 90 m.min^{-1}.

Data are presented as mean ± SD.
*Significant difference from 5-7 years ($P < 0.05$).

No significant associations were detected between percent bias and BMI, WC, or %BF when added separately as covariates to the repeated measures ANOVA (Sex by Age Group by Speed). However, pedometer tilt angle was associated with mean percent bias for both pedometers (SW-200, $F = 22.689$, $P < 0.001$; NL-2000, $F = 6.310$, $P = 0.014$). Adjusting for tilt angle did not negate the significant difference in mean percent bias between sexes (SW-200, $F = 11.516$, $P = 0.001$; NL-2000, $F = 6.276$, $P = 0.014$) or between age groups for the NL-2000 ($F = 8.690$, $P = 0.004$). However, no significant interactions were detected between tilt angle and sex (SW-200, $F = 0.002$, $P = 0.961$; NL-2000, $F = 0.519$, $P = 0.474$) or between tilt angle and age group (SW-200, $F = 0.277$, $P = 0.600$; NL-2000, $F = 0.002$, $P = 0.962$). Further analysis revealed significant partial correlation coefficients between percent bias and tilt angle (controlled for sex, age, BMI, WC, and %BF) for the SW-200 pedometer at slow ($r = -0.465$), moderate ($r = -0.506$), and fast ($r = -0.404$) walking speeds ($P < 0.001$ for all). These results suggest that tilt angle has a significant effect on SW-200 error regardless of sex, age, walking speed, or body composition. Similar results were obtained for the NL-2000 pedometer at slow ($r = -0.298$; $P = 0.009$) and moderate speeds ($r = -0.258$; $P = 0.025$), but not at fast speeds ($r = -0.010$; $P = 0.935$).

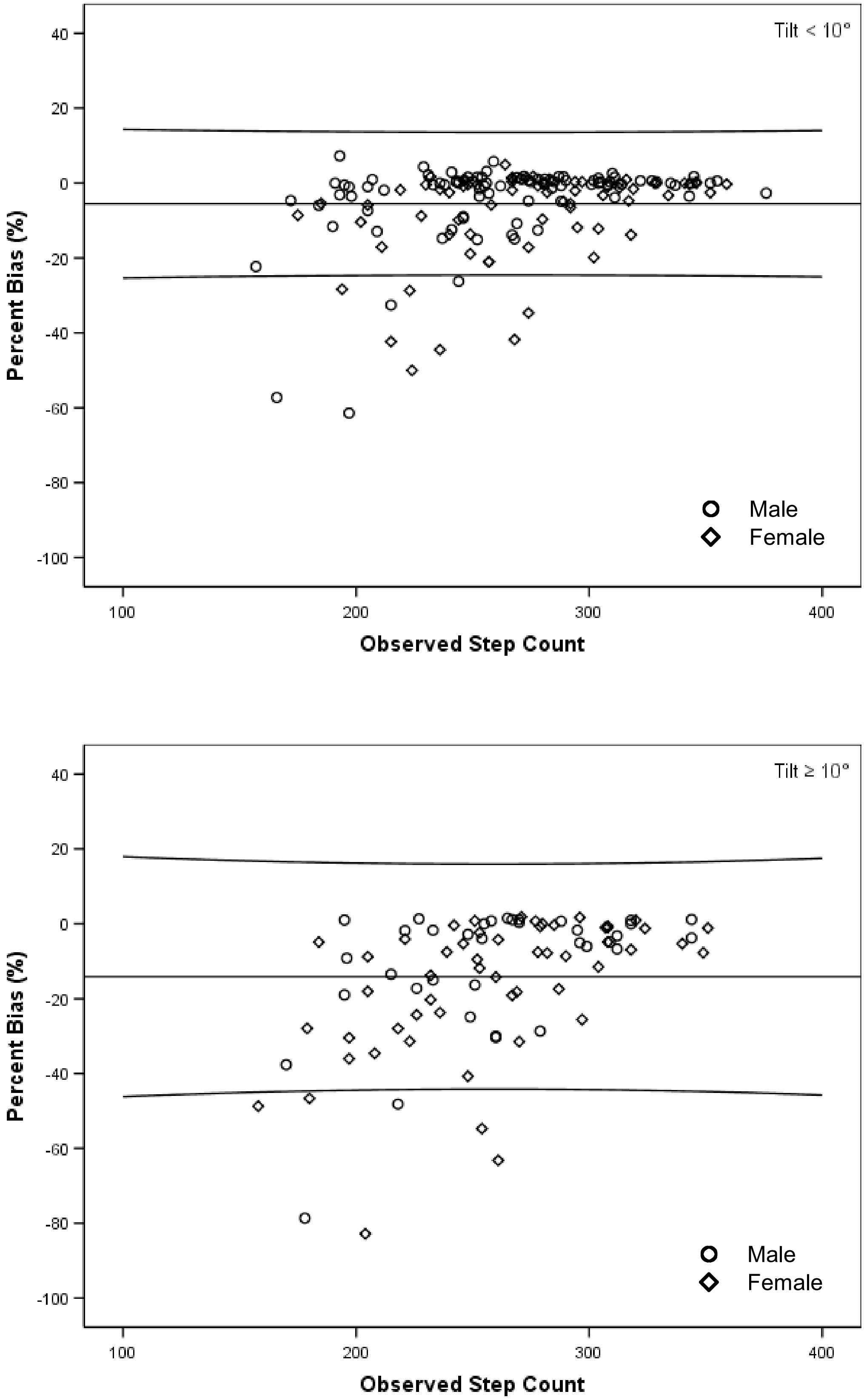

Figure 2-4. Modified Bland-Altman plots showing percent bias of the SW-200 pedometer for children at walking speeds of 42-90 m.min^{-1}.

Data for the two tilt angle groups (< 10° and ≥ 10°) are presented separately with mean percent bias (straight line) and 95% prediction interval (curved lines).

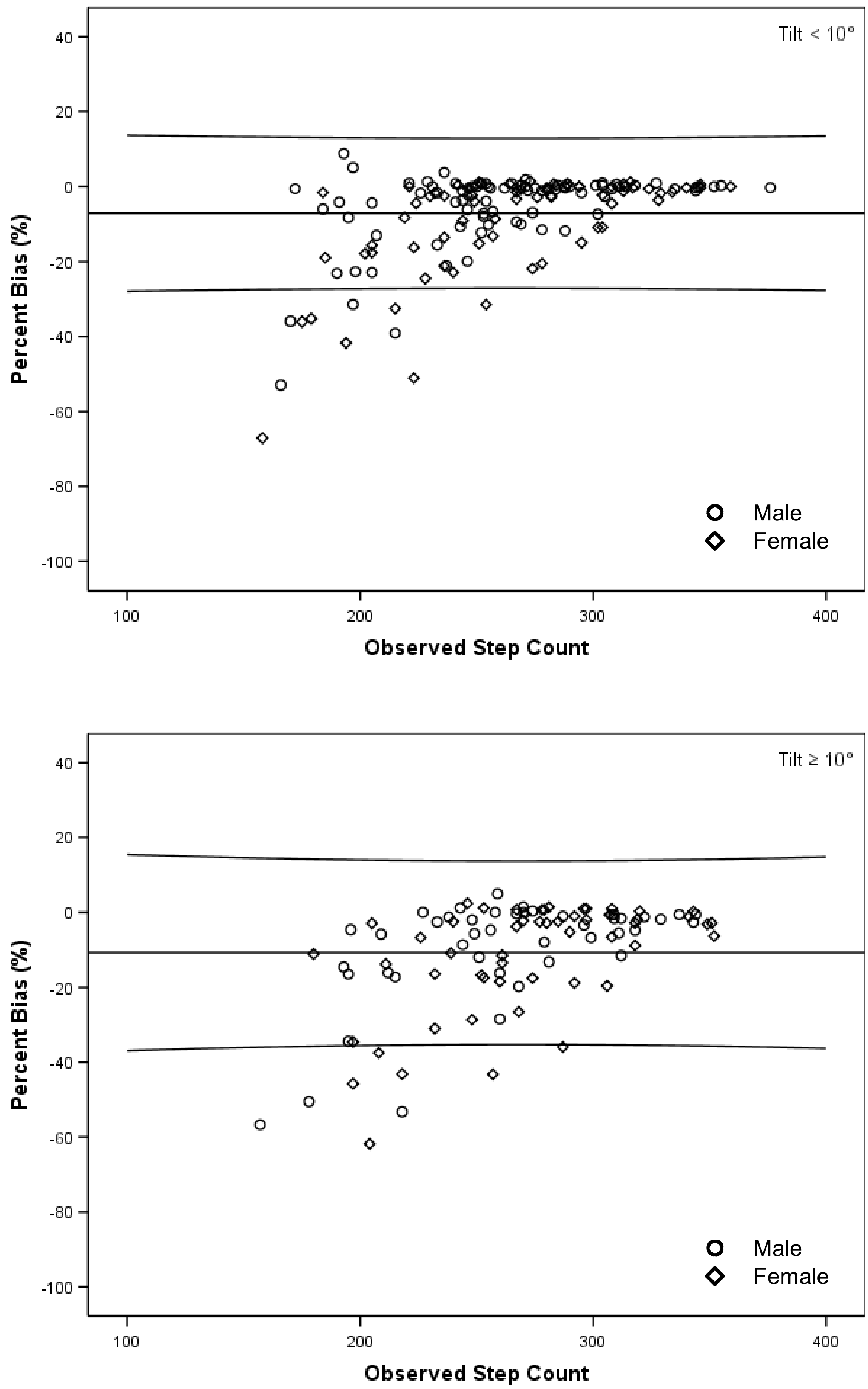

Figure 2-5. Modified Bland-Altman plots showing percent bias of the NL-2000 pedometer for children at walking speeds of 42-90 $m.min^{-1}$.

Data for the two tilt angle groups (< 10° and ≥ 10°) are presented separately with mean percent bias (straight line) and 95% prediction interval (curved lines).

Figure 2-4 and Figure 2-5 show the effects of tilt angle on the percent bias of both pedometers at all three measurement speeds. In total, 35.7% and 39.3% of the sample had large (≥ 10°) tilt angles when wearing SW-200 and NL-2000 pedometers, respectively. For the SW-200 pedometer, percent bias increased from -5.5 ± 11.5% in children with small (< 10°) tilt angles to -14.1 ± 18.0% in children with large tilt angles ($t = 4.110$, $P < 0.001$). Differences between small and large tilt angle groups were less pronounced for the NL-2000 pedometer, with percent bias increasing from -7.1 ± 12.1% to -10.7 ± 14.7%, respectively ($t = 2.055$, $P = 0.041$). A large tilt angle also resulted in wider 95% prediction intervals, particularly for the SW-200 pedometer. Additional analyses (not shown) revealed that this reduction in precision was independent of sex or age group for both pedometers.

Discussion

In this study, we investigated the effects of walking speed, age group, and body composition on the accuracy of two types of pedometer for measuring steps in children. Our results show that spring-levered (SW-200) and piezoelectric (NL-2000) pedometers provide acceptable estimates of step count during moderate and fast walking, but undercount steps by approximately 20% at a slow walking speed. This is consistent with previous research that reported a significant decrease in pedometer accuracy at speeds below 54-58 m.min^{-1},[12,173] and suggests that the vertical acceleration forces generated during slow walking in children frequently fall below the 0.35 g required to register a step in the pedometers tested. Furthermore, the associations between the percent bias and observed steps at slow and moderate speeds indicate that the degree of underestimation decreased with the number of steps taken. A possible explanation for this result is that children who take long, controlled steps during slow/moderate walking may generate less vertical acceleration forces (and therefore more undetected steps) than those who have short, jolting gaits. Differences in walking style may also account for the smaller overall bias observed for boys when compared with girls.

A potential solution to the systematic undercounting of SW-200 and NL-2000 pedometers at slow speeds is to lower the force threshold for step detection. However, the subsequent increase in sensitivity would be accompanied by a reduction in specificity under free-living conditions, such that a greater number of non-step movements (e.g., jolting during car travel) would be incorrectly interpreted as steps.[130] It is therefore relevant to consider whether reducing undercounting at slow speeds merits the increase in error from artificial sources. It could be argued that slower steps require less energy expenditure and are therefore less important to detect than steps achieved at faster speeds. On the other hand, given that the relationships between various walking speeds and health benefits are not well understood, it may be presumptive to label a specific walking speed as 'unimportant'. The first step is to investigate the trade-off between sensitivity and specificity that arises from altering the step detection threshold of pedometers in free-living conditions.

As with pedometer accuracy, the precision of step count estimates was also lower at a slow walking speed. The wide 95% limits of agreement observed at a speed of 42 $m.min^{-1}$ imply that only inter-individual differences greater than 37.6% and 31.9% could be confidently identified by SW-200 and NL-2000 pedometers, respectively. For a child averaging 15,000 $steps.day^{-1}$, this corresponds to a detectable difference of ± 5,640 (SW-200) and ± 4,785 (NL-2000) steps. These limits narrow to ± 2,385 and ± 1,770 steps for moderate walking, and to ± 990 and ± 555 steps for fast walking. Given that the smallest meaningful difference in activity is generally considered to be 1,000 $steps.day^{-1}$,[224] it follows that both pedometer models are effective for detecting change during fast walking only. However, it should be noted that a larger test sample would almost certainly result in smaller limits of agreement for all speeds. The loss of precision is a more important statistic for population research, as it indicates the theoretical increase in sample size required to offset the random error associated with pedometers. Our results suggest that the sample size must be increased by 109% to compensate for the use of SW-200 pedometers (as opposed to a hand counter) during slow walking (67% for NL-2000), but only by 7% when measuring fast walking (3% for NL-2000).

Our results clearly support the view that pedometers are less effective for measuring children's steps at slow compared with fast walking speeds. However, the relevance of this finding is uncertain given that little is known about the speeds at which children normally walk in free-living conditions. If slow walking is not a frequent occurrence in children, then the inaccuracy of pedometers at these speeds is less of a concern. Beets *et al*.[12] reported that pedometer performance during self-paced walking was similar to that observed during treadmill walking at a brisk speed (80 $m.min^{-1}$). Indeed, all 20 children tested moved at speeds above 65 $m.min^{-1}$ when asked to walk normally around an athletic track, suggesting that speed-related pedometer error may not be an issue during self-paced walking in children. Nonetheless, the speeds at which children move during other activities (e.g., free play or sports) are not known. The recent development of portable global positioning units that are able to record spatial location at high sampling frequencies may provide researchers with a means to collect this information.

The accuracy of pedometers in different age groups was also examined in the present study. Given that young children tend to exhibit a less mature gait[112] and generate lower GRF[207] than older children, we hypothesised that the number of undetected steps would be greater in participants from Years 1-2 than those from Years 5-6. On the contrary, the percent error for both pedometers was highest in older children. It appears likely from our observations that the limited ability of younger children to modulate walking frequency on a treadmill[112] induced a jolting gait that generated abnormally large GRF. This would explain the age-specific trends observed in the present study, but also raises concerns over the use of treadmills to simulate typical walking in young children. The likelihood of uncharacteristic walking patterns could be reduced by assessing overground walking in young children; however it is difficult to regulate walking speed when using this method. In any case, our results suggest that age-related variation in pedometer performance is only relevant during slow walking speeds.

Given recent moves to prescribe step count targets for children based on overweight status,[63,224] it is vital that pedometers are able to accurately measure physical activity in children with excess adiposity. We chose to include both overweight and non-overweight children in order to examine the association between body composition and pedometer validity across a wide range of body sizes. The present results confirm that tilt angle is a more important contributor to pedometer error than adiposity, which is consistent with previous findings in obese adults.[48] In fact, none of the three body composition measures tested (BMI, WC, and %BF) showed significant associations with percent bias (when adjusted for all other independent variables). In contrast, an absolute tilt angle $\geq 10°$ corresponded to a 2.6- and 1.5-fold increase in step count underestimation for the SW-200 and NL-2000 (respectively) when all three speeds were combined. Our analyses also revealed that the effects of tilt angle on mean percent bias were relatively constant across sex and age groups. The precision of step count estimates also decreased markedly in individuals with large pedometer tilt irrespective of sex or age group, particularly for the SW-200 model.

These findings suggest that variables other than body composition are responsible for the degree of pedometer tilt in children. In our study, a large tilt angle was observed in over a third of the participants but was unrelated to BMI, WC, or %BF. We propose that the style of waistband on the clothing worn by the child is the most important determinant of pedometer tilt. It was apparent from our observations that attaching a pedometer to loose waistbands with limited elasticity often resulted in the pedometer tilting away from the vertical plane. Thus, children with unsuitable clothing may experience a reduction in pedometer accuracy regardless of their body size. Although they did not measure tilt angle, Ramírez-Marrero *et al.*[173] noticed that bias at slow walking speeds decreased after moving the pedometer from the midline of the thigh (as per the manufacturer's instructions) to a pouch secured by a belt around the waist. This suggests that fastening the pedometer to a belt system rather than relying on the existing clip on the back of the pedometer may improve stability and minimise undercounting of steps. However, there are currently no pedometer manufacturers that provide this option.

To our knowledge, the present study is the first to validate the piezoelectric NL-2000 pedometer in a paediatric sample. The NL-2000 showed similar accuracy and better precision than the spring-levered SW-200 pedometer, with noticeably superior performance at large tilt angles. The latter disparity between models appears even greater in obese adults; Crouter *et al.*[48] reported a significant association between tilt angle and absolute error for the SW-200 but not the NL-2000. A possible explanation is that the GRF produced by obese adults when walking is large enough to overcome the dampening effects of excessive tilt in piezoelectric pedometers. Our results suggest that while the walking forces generated by children are not sufficient to offset all tilt-related error in NL-2000 pedometers, their accuracy and precision is less compromised by a large tilt angle than the spring-levered SW-200 pedometer. The MDM capabilities of the NL-2000 are another prospective benefit for researchers, however the greater cost of the NL-2000 ($60) compared with the SW-200 ($17) may preclude its use in large-scale studies. The purchase of multiple belt systems (if developed) to reduce tilt-related error may be another financial issue to consider.

In summary, SW-200 and NL-2000 pedometers show acceptable accuracy and precision for recording step counts in children at moderate and fast walking speeds, but not at slow walking speeds. Pedometer bias was not affected by body composition, but was positively associated with and absolute tilt angle for both pedometers. Our results also suggest that piezoelectric pedometers provide a more precise estimation of children's step counts than spring-levered models. In order to minimise tilt angle and reduce measurement error, we recommend the development of a firm elastic belt system for using pedometers to measure steps in children.

CHAPTER 3

PEDOMETER REACTIVITY IN CHILDREN

Preface

The preceding chapter established that the performance of the NL-2000 pedometer for recording steps in children is comparable to the widely used Yamax SW-200 pedometer. While this provides support for the use of NL-2000 pedometers in the main descriptive study of this thesis, the potential reactivity of children to wearing pedometers remains a concern. The only studies to investigate pedometer reactivity in children used an assessment protocol that required researchers to visit the participants each morning to manually record the steps for the previous day. It is possible that this high level of contact prompted children to accumulate atypically high steps over the entire monitoring period, thereby masking the potential reactivity that would normally occur using pedometers that limit participant/researcher interaction (multiday memory). To elucidate this issue, the study in this chapter was designed to investigate changes in step count patterns over four 24-hour periods using the NL-2000 pedometer. The absence of reactivity would justify the selection of the NL-2000 for measuring physical activity in the principal study. The paper resulting from this chapter is currently under review for publication in the *International Journal of Behavioural Nutrition and Physical Activity*.

Abstract

Objectives: Although previous research using conventional pedometers in children has yet to show evidence of reactivity, it remains possible that the presence of researchers to collect data each morning may stimulate children to accumulate artificially high step counts for the duration of the monitoring period. The primary purpose of this study was to investigate the reactivity of children to wearing a new model of pedometer that minimises participant/researcher interaction. Secondary objectives were to (1) examine the effect of providing background information and instruction before testing, and to (2) determine the number of monitoring periods required for reliable step count estimates.

Methods: Sixty-two children (27 boys, 35 girls) aged 5-11 years wore sealed multiday memory pedometers for four consecutive 24-hour periods. Reactivity was defined as a significant difference in steps between the first and last test periods.

Results: Mean step counts for this sample were 14,657 ± 2,830 (boys) and 12,338 ± 2,517 (girls). No significant difference in step counts was detected between the first and last test periods, regardless of sex or prior instruction. However, a significant decrease in steps associated with high levels of rainfall was observed. Correlation analyses suggest that four 24-hour periods are acceptable for obtaining reliable step count estimates in children (ICC = 0.78).

Conclusions: Our results indicate that children are not reactive to wearing pedometers even when participant/researcher interaction is reduced. Furthermore, providing children with an explanation of the function and purpose of the pedometer did not affect step count patterns. The reduction in steps on days of high rainfall suggests that weather conditions may be an important consideration when quantifying activity in children.

Introduction

Regular physical activity during childhood can improve bone health, blood lipid profile, self-efficacy, and can reduce the risk of obesity and hypertension.[20] As such, the promotion of an active lifestyle for young people is a key public health priority in many countries. However, obtaining valid and reliable estimates of physical activity within paediatric populations has proven challenging. It is generally accepted that children do not possess the cognitive ability to accurately recall previous behaviour, and accordingly self-report questionnaires are rarely implemented in youth below 10 years of age.[184] Proxy reports are a commonly used alternative that are based on the approximation of children's physical activity patterns by an adult observer (i.e., usually a parent). Although relatively cost-effective, these subjective techniques often result in imprecise estimates of physical activity.[158,172,184]

Pedometers are small step-counting devices that provide an accurate yet inexpensive measure of free-living physical activity in people of all ages.[225] An obvious concern in children is the potential for pedometers to act as a stimulus to accumulate as many steps as possible over an assessment period. Vincent and Pangrazi[236] investigated children's reactivity to wearing sealed pedometers during out-of-school hours, and reported no significant differences in mean step counts among eight days of testing. A similar study by Ozdoba *et al*.[163] found that reactivity was minimal even when children were able to observe the number of steps they were achieving each day. However, both studies used pedometers (Yamax Digiwalker SW-200) that required researchers to visit the children each day in order to record daily step counts. This practice provides constant reminders to the children that they are part of a study, and may promote a higher level of daily activity over the entire monitoring period. Atypical increases in step counts may mask a decline in activity associated with habituation, and thus any reactivity to wearing pedometers may be missed. Until recently, the only way for researchers to minimise their potential influence on daily activity has been to rely on participants to record their own step counts. Despite the potential advantages of this approach, obtaining accurate estimates of self-reported step count data in children is often difficult due to recording errors and/or deliberate misrepresentation.[149,215]

New developments in pedometer technology have provided more options for researchers, enabling physical activity assessment to proceed without daily contact or reliance on self-reported step counts. To our knowledge, this study is the first to analyse children's step count changes over time with pedometers that automatically store data in 24-hour blocks. The use of sealed multiday memory (MDM) pedometers allowed pedometer reactivity to be assessed while restricting contact with the children to before and after the test period, thereby negating the possibility of researcher-induced reactivity. A secondary objective was to determine if children who are provided with an explanation of the purpose and operation of pedometers prior to monitoring react differently to children who are not given operational information. Given the importance of establishing a standard preparation protocol that minimises pedometer reactivity in children, the present study directly compared day-to-day step count patterns using the two distinct approaches.

In addition, we compared the adequacy of two, three, and four successive 24-hour periods for obtaining reliable estimates of habitual activity in children. In one of the key reliability reviews devoted to physical activity research, Baranowski and de Moor[9] proposed that an intraclass correlation coefficient (ICC) greater than or equal to 0.80 is indicative of an acceptable level of reliability. Although previous research has established that 4-5 days are sufficient to achieve reliable activity scores using accelerometers in children,[111,218] relatively few studies have examined the stability associated with pedometers. Vincent and Pangrazi[236] managed to achieve an ICC greater than 0.80 after five days of monitoring out-of-school pedometer steps in children. Remarkably, Ozdoba *et al*.[163] reported a similar level of stability after only two of four weekdays of step count data. However, the latter result is questionable given that 39% of the participants had one or two days of missing data substituted with the average step count for the remaining days. To avoid artificial inflation of the ICC, the present study only included participants with complete datasets over all four monitoring periods.

Finally, variation in weather patterns across the testing periods enabled us to investigate the relationship between rainfall and free-living physical activity in children. This issue is rarely mentioned in the literature, and yet the potential implications of weather-related physical activity patterns in children are significant. As a consequence, we have quantified the association between hours of rainfall and children's daily step counts.

Methods

Participants

One hundred and seventy-two children (88 boys, 88 girls) aged 5-11 years were randomly selected from two neighbouring primary-level (elementary) schools in Auckland, New Zealand. Approval for the study was obtained from the principals of both schools, and from the institutional ethics committee (Appendix C). From the 110 children (64%) who provided parental consent, 88 were selected to participate in the study. Of the initial group, three participants either lost or unsealed their pedometer during testing. A further 23 provided incomplete data and were excluded from analysis, resulting in a final sample size of 62 (27 boys, 35 girls). A CONSORT (Consolidated Standards of Reporting Trials) flow diagram outlining the recruitment and exclusion processes is presented in Figure 3-1. The mean age of participants differed significantly ($P < 0.001$) between School 1 (7.8 ± 1.8 years) and School 2 (9.3 ± 1.5 years). However, preliminary analysis revealed no significant association between mean step count and age in this sample ($P = 0.495$). Selected schools were located within a close distance to each other (< 1 km), ensuring that the effects of the weather and/or socioeconomic status on activity levels were comparable for all participants.

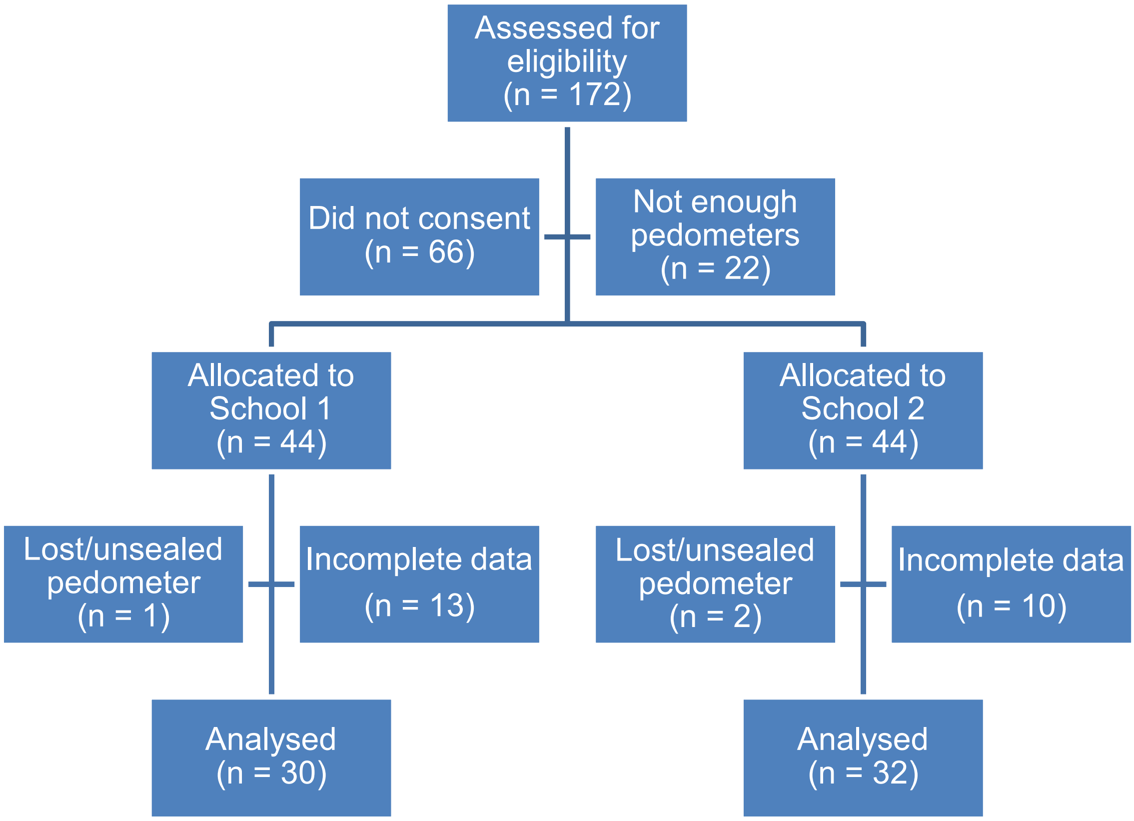

Figure 3-1. CONSORT diagram showing the flow of participants through the present study.

Measures

The New Lifestyles NL-2000 (Lee's Summit, MO) MDM pedometer was used to count steps. Previous research has shown that the NL-2000 offers similar accuracy and better precision for measuring steps in children than the widely used Yamax SW-200 pedometer.[64] The NL-2000 pedometer has a seven-day recording cycle that is facilitated by an internal clock. At a specific time of day preset by the researcher, the pedometer resets to zero while storing the step count for the preceding 24-hour period in the first available timeslot (up to a maximum of seven). In this way, researchers can access the steps for each 24-hour period without visiting participants until the conclusion of monitoring.

Procedures

The internal clock in each MDM pedometer was preset to commence recording cycles at 11:00am. Pedometers were then sealed with cable ties, and distributed to all participants on Monday at 10:50am. Using this method, four 24-hour monitoring periods were recorded prior to collection of the pedometers on Friday afternoon. Participants were subjected to one of two pre-test protocols depending on the school they attended. Before receiving their sealed MDM pedometers, children assigned to Protocol 1 ($n = 30$) were given an explanation of the pedometer's function, a demonstration by a researcher, and the opportunity to play with an unsealed pedometer for 10 minutes. Children assigned to Protocol 2 ($n = 32$) received sealed pedometers without playing with an unsealed unit or an explanation of their purpose. All participants were instructed to attach the pedometer to the waistline of their clothing above the right knee, and to wear it all the time except when swimming or sleeping. Physical activity schedules for both schools were identical across all four monitoring periods.

Data Treatment

To determine participant compliance, a questionnaire was completed by the parents/caregivers of each participant the day before pedometer collection (Appendix I). This technique was chosen as it avoids the shortcomings associated with self-reported activity surveys in younger populations.[184] However, a standard non-compliance time period above which data are discarded has yet to be established. Data treatment procedures used in previous studies have been inconsistent, ranging from the inclusion of all daily pedometer data regardless of participant compliance[215] to the exclusion of all participants who removed their pedometer for more than one hour on any given day.[248] Although the latter criterion results in a greater number of exclusions, it also provides the most accurate estimates of daily steps. Thus, children in the present study who were not wearing their pedometer for more than one hour during any of the 24-hour monitoring periods were excluded from our analysis. Twenty-three of the 88 initial participants (26.1%) fell into this category. Participant non-compliance during school hours was considered negligible due to teacher assistance.

Statistical Analyses

Step count data were entered into a SPSS version 12 (SPSS Inc, Chicago, IL) spreadsheet for statistical analysis. Associations among monitoring period, sex, and protocol were assessed using a factorial repeated measures ANOVA (Sex by Protocol by Period). Paired t-tests were also used to directly examine differences in steps between two periods. Changes in steps between periods were investigated using independent samples t-tests. Correlation analyses were used to determine reliability among test periods. An alpha level of 0.05 was used for all statistical tests.

Results

Mean daily step counts for this sample were 14,657 ± 2,830 for boys and 12,338 ± 2,517 for girls. Table 3-1 presents the results of a 2 x 2 x 4 factorial repeated measures ANOVA (Sex by Protocol by Period). Mean step count differed significantly among the four test periods ($P < 0.001$). However, no significant interactions existed between sex and period ($P = 0.057$), between pre-test protocol and period ($P = 0.318$), or among sex, protocol and period ($P = 0.121$). Significant differences in mean step counts were detected between boys and girls ($P = 0.001$), but not between the two pre-test protocols ($P = 0.113$).

Table 3-1. Results of a factorial repeated measures ANOVA (Sex by Protocol by Period).

Source	*F*	*P*
Within subjects		
Period	28.737	0.000[a]
Period x Sex	2.549	0.057
Period x Protocol	1.184	0.318
Period x Sex x Protocol	1.966	0.121
Between subjects		
Sex	12.327	0.001[a]
Protocol	2.591	0.113
Sex x Protocol	0.043	0.836

[a]Significant ($P < 0.01$) level.

Despite the association between test period and mean step count over the four-day timeframe, a paired t-test revealed no significant differences between step counts for Period 1 and Period 4 ($P = 0.145$). If participants were reactive to wearing pedometers, we would expect significantly fewer steps to be accumulated in the last period (4) compared with the first period (1). In addition, an independent samples t-test (unequal variances) was implemented to compare the change scores for the first and last test periods grouped according to either pre-test protocol (Protocol 1 or Protocol 2) or sex (male or female). Results indicate that there were no significant effects of protocol ($P = 0.400$) or sex ($P = 0.614$) on the change in steps between Period 1 and Period 4.

This provides strong evidence that reactivity does not exist in this sample, irrespective of sex or pre-test protocol.

The association between test period and mean step count presented in Table 3-1 can be explained by a decrease in mean steps during Periods 2 and 3. Figure 3-2 shows the mean step counts for male and female participants overlaid with total hours of rainfall during daylight hours (7:00am to 7:00pm) for each test period (as recorded by the Meteorological Service of New Zealand, Ltd). Data from both pre-test protocols were combined due to the non-significant effect on step count (Table 3-1). It is likely that the increase in rain hours during Periods 2 and 3 is associated with less activity and fewer pedometer steps compared with the other two periods. To investigate this hypothesis, a paired t-test was used to compare mean steps for Periods 1 and 4 (no rain hours) with mean steps for Periods 2 and 3 (5-7 rain hours). Following the detection of a significant difference ($P < 0.001$), a standardised effect size of 0.76 was calculated to quantify the relationship between rainfall hours and step count (95% CI = 0.55 to 0.97). This equates to a 16.4% decrease in the number of steps accumulated during rainy days versus non-rainy days (95% CI = 11.9% to 21.0%).

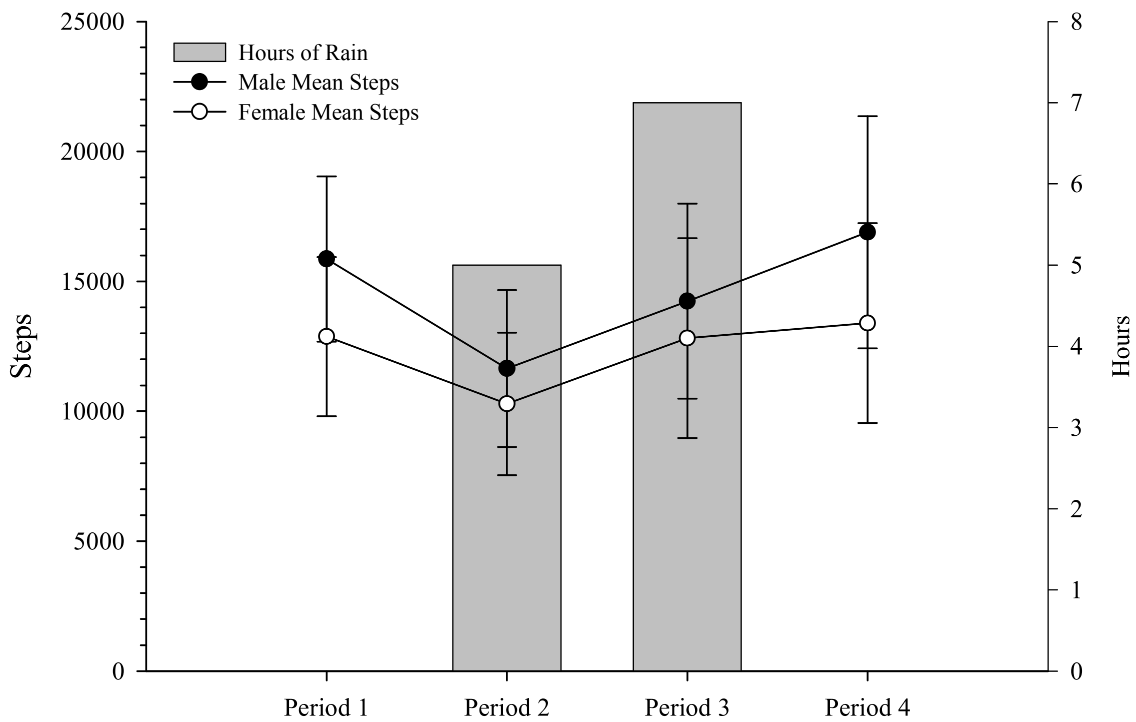

Figure 3-2. Mean step counts (± SD) by sex over four 24-hour monitoring periods presented with daylight hours of rainfall.

Table 3-2 shows the results of stability reliability analysis using the ICC and 95% confidence intervals. ICC increased from 0.59 after two test periods, to 0.68 after three test periods, and to 0.78 after four test periods. We also estimated the number of 24-hour monitoring periods that would be required to improve the alpha correlation to 0.80 and 0.90. First, the single measure intraclass correlation coefficient (ICC_1) was given by:

$$\mathrm{ICC}_1 = \frac{MS_b - MS_w}{MS_b + \left(\left(\frac{k}{k'} - 1\right) \times MS_w\right)}$$

where MS_b is the between subject mean square, MS_w is the within subject mean square, k is equal to 4 (the total number of periods), and k' is equal to 1 (the number of periods for which ICC_1 is estimated). This equation resulted in an ICC_1 of 0.47, which represents the typical correlation for any one of the four measurement periods. Calculation of the requisite number of assessment periods was then given by:

$$k = \left(\frac{\mathrm{ICC}}{1 - \mathrm{ICC}}\right) \times \left(\frac{1 - \mathrm{ICC}_1}{\mathrm{ICC}_1}\right)$$

where ICC in this instance was either 0.80 or 0.90. Using this equation, $k = 4.51$ when ICC = 0.80, and $k = 10.15$ when ICC = 0.90. In other words, our dataset indicates that five and eleven periods of monitoring (with one period equivalent to one weekday) are required to obtain an ICC greater than 0.80 and 0.90, respectively.

Table 3-2. Pedometer reliability analysis using ICC and 95% CI.

Number of 24-hour Periods	Intraclass Correlation Coefficient	95% Confidence Intervals
2 periods	0.59	0.32-0.75
3 periods	0.68	0.50-0.79
4 periods	0.78	0.68-0.86

Discussion

This study investigated children’s reactivity to wearing sealed MDM pedometers over four 24-hour monitoring periods. The data storage capabilities of MDM pedometers provide a considerable advantage for physical activity researchers, who are no longer required to record daily steps on each morning of an assessment period. Our results showed no evidence of reactivity using this method, with no significant difference in step counts between Assessment Periods 1 and 4 for either males or females. In addition, no significant differences in the change in steps over time were detected between children that were familiarised with pedometers and children who were given no information. Thus, the procedure used to prepare children for testing does not appear to affect their reactivity to wearing pedometers.

This study also confirmed findings from previous research using conventional pedometers in smaller samples of children.[163,236] It was originally hypothesised that regular interaction between investigators and child participants may stimulate daily reactivity to wearing a pedometer. If so, the decrease in activity over time synonymous with reactivity may not eventuate in studies using conventional pedometers. However, such a decrease did not occur even when participant/researcher contact was minimised by implementing MDM pedometers. These results show that children are unlikely to increase their activity in response to frequent visits from researchers, and provide support for the use of conventional pedometry to gather daily step counts during school days. Nonetheless, obtaining weekend estimates of activity is straightforward when using MDM pedometers. This capability is especially important given that children's activity levels tend to be lower on weekends than on weekdays.[81,181]

The significant association between rainfall hours and the step counts of participants in this study highlights the importance of recording weather patterns in future physical activity research. Ozdoba *et al*.[163] raised this issue after noticing rain on one day of their assessment period, but did not quantify the relationship with mean step count. More recently, Chan *et al*.[36] showed that rainfall can reduce activity in adults by 5.2 to 8.3%. The 16.4% reduction observed in the present study suggests that rainfall may have an even stronger effect on children's physical activity. Interestingly, the lowest period of activity did not occur during the period with the highest number of rainfall hours. A possible explanation is that rain during a one hour lunch break will have a greater effect on step count than rain during the five hours children are in class. Alternatively, there may be other confounding factors not identified in this study that may have resulted in the decrement in mean steps during Periods 2 and 3. In any case, the potential effect of other adverse weather conditions (e.g., high winds, extreme temperatures, snowfall) on pedometer steps in children warrants further investigation.

Pedometry research looking at the number of monitoring days required for reliable estimates of children's habitual activity is equivocal. Vincent and Pangrazi[236] concluded that three to four days were sufficient in their study of out-of-school activity. This was shortened to only two days by Ozdoba *et al*.[163], although this may be largely attributable to data treatment procedures that promote an inflation of the ICC. We did not observe such a high degree of reliability, reaching an ICC of 0.78 after four 24-hour monitoring periods. Although our data indicate that an additional period would have resulted in an ICC above 0.80, these estimates are conservative given the fluctuating weather patterns experienced during testing. Thus, four measurement periods of physical activity (equivalent to four weekdays) appears sufficient for achieving reliable results in children. Still unresolved is the number of weekends necessary for reliable pedometer measurements in young people. To our knowledge, the only assessment of pedometer reliability in children during weekends was limited by self-reported step count data.[179] MDM pedometers currently provide the best solution to this problem, enabling weekend steps to be recorded while avoiding the inaccuracies associated with self-report techniques.

It should be noted that comparisons of reliability among studies are problematic given that the ICC is sensitive to the heterogeneity of values between subjects.[99] For example, a wide spread of values between participants will lead to high between-subject variance with respect to the within-subject variance, and consequently the ICC will approach 1. Another study with the same within-subject variance but a lower spread of values between participants will invariably report a smaller ICC. Without knowledge of the within- and between-subjects variance in each study sample, it is difficult to determine which source of variance contributes most to the discrepancies observed in previous reliability research.

In summary, we found no evidence of reactivity to wearing MDM pedometers in children. This corroborates similar findings from studies using conventional pedometers.[163,236] Nonetheless, we recommend the use of MDM pedometers where possible given the logistical advantages for researchers. Physical activity levels in the present study were not affected by fully informing children prior to testing, although a significant decrease was observed during periods of high rainfall. Finally, our results suggest that four weekdays of monitoring with MDM pedometers provides a reliable assessment of physical activity in children.

CHAPTER 4

WEATHER AND PEDOMETER STEPS IN CHILDREN

Preface

This chapter represents the first interpretation of findings from the main study in this thesis. Despite the negative effects of rainfall observed in Chapter 3, the association between meteorological variables and physical activity in children has not been previously investigated. This is an important issue given that differences in weather may mask the effects of physical activity interventions, or confound comparisons between socio-demographic groups. The collection of pedometer steps in a large sample of New Zealand children provided the opportunity to elucidate this issue by examining weather-related changes in activity behaviour. It should be noted that the paper that forms the bulk of the chapter was completed after the publications that arose from Chapters 5-7. Thus, only a brief description of the methods is provided here; a full account can be found in Chapter 5. The paper resulting from this chapter is currently under review for publication in the *Medicine and Science in Sports and Exercise*.

Abstract

Objectives: To evaluate the effects of weather conditions on the number of pedometer steps accumulated by children on weekdays and weekend days.

Methods: A total of 1,115 children (536 boys, 579 girls) aged 5-12 years wore sealed multiday memory pedometers for three weekdays and two weekend days. Daily values (between 7am to 7pm) for mean ambient temperature, mean wind speed, precipitation, and the duration of bright sunshine were obtained from local meteorological stations. Day length was calculated from sun rise and sun set times. The effects of the five weather variables on step counts were assessed using mixed linear model analysis.

Results: In boys, a 10ºC rise in mean ambient temperature was associated with a 10.5% increase in weekday step counts and a 26.4% increase in weekend step counts. The equivalent increase in temperature resulted in a 16.2% increase in weekday step counts in girls, with an unclear effect on weekend step counts. Corresponding effect magnitudes across age and SES groups were also variable, ranging from trivial to moderate. Substantial decreases in weekday and weekend step counts were observed during moderate rainfall (1.1-4.9 mm) for all sex, age, and SES groups. The effects of changes in day length, wind speed, and hours of bright sunshine on daily step counts were largely trivial or unclear.

Conclusions: The impact of rainfall and mean ambient temperature on children's daily step counts suggests that these variables should be considered when comparing physical activity levels across different locations or time periods. Developing physical activity options that are appropriate for cold and/or rainy days is likely to have beneficial effects on children's activity levels.

Introduction

Regular physical activity during childhood can improve bone health, blood lipid profile, self-efficacy, and can reduce the risk of obesity and hypertension.[20] Consequently, increasing physical activity in young people is a key public health priority in many countries. Given the increasing support for initiatives that encourage children to adopt or maintain an active lifestyle, it is essential that the determinants of physical activity in this age group are well understood. Previous research has identified numerous demographic, sociocultural, psychological, cognitive, and behavioural factors related to physical activity in young people.[185] However, there is limited information describing the interactions between children's activity patterns and the physical environment.

An environmental factor often overlooked in previous research concerns the effect of inclement weather on physical activity. Periods of heavy rainfall, strong wind, and low temperatures are not conducive to outdoor play, and may result in a reduction in overall activity levels. This prospect has important implications for the surveillance of children's physical activity, as comparisons between samples from distinct geographical locations may be affected by differences in weather conditions. The evaluation of physical activity levels pre- and post-intervention may also be confounded by meteorological variation. Furthermore, an appreciation of the environmental barriers to physical activity in children is requisite for developing strategies that promote physical activity in all weather conditions.

While numerous surveys have noted that physical activity participation in temperate climates tends to be highest in summer and lowest in winter,[10,19,35,53,145,223,230,233] few have elucidated the specific weather-related variables responsible for seasonal differences. Togo *et al*.[212] reported that activity in Japanese older adults increased with mean ambient temperature between -2 and 17°C and decreased between 17 and 29°C, with an exponential decrease in activity as precipitation increased. Similarly, Chan *et al*.[36] described a 2.9% increase in physical activity for every 10°C rise in mean ambient temperature among Canadian adults, and a 5.2-8.3% decrease during periods of rainfall. Other meteorological factors negatively associated with activity included maximum wind speed, total snowfall, and the amount of snow on the ground.

The only study to consider the effects of multiple weather-related variables on children's physical activity reported inconsistent findings. In their sample of UK children aged 11-12 years, Brodersen *et al*.[25] showed that rainfall reduced activity levels in girls, and that sedentary behaviour was more common at low temperatures than at high temperatures in boys. However, activity data were collected using a self-report questionnaire that assessed the frequency of vigorous exercise only. Given that vigorous exercise typically represents only a small proportion of overall activity,[175,219] the impact of variable weather patterns on habitual physical activity in children remains uncertain. Also unresolved is the potential difference between weather effects on weekdays and weekend days. For example, it is possible that the structured physical activity that occurs at school is less affected by weather conditions than weekend activity.

The purpose of the present research was to characterise the effects of a series of meteorological variables (day length, rainfall, temperature, wind speed, and the duration of bright sunshine) on the number of pedometer steps accumulated by children on both weekdays and weekend days. In addition, associations between weather variables and activity were compared across a range of sex, age, and socioeconomic groups. This study represents the first investigation of objectively measured physical activity and weather conditions in children.

Methods

This study represents a secondary analysis of an existing dataset. The recruitment and physical activity procedures have been described in detail elsewhere,[62] with only a brief overview given here. However, the collection and treatment of meteorological data and the statistical analyses are novel aspects of the study and are explained in full.

Participants

A total of 1,115 children (536 male, 579 female) aged 5-12 years were randomly selected from 27 primary (year levels 1-6) schools in Auckland, New Zealand. The ethnic composition of this sample was 549 European children (49.2%), 334 Polynesian children (30.0%), 184 Asian children (16.5%), and 48 children from other ethnic groups (4.3%). Socioeconomic status (SES) was estimated using the Ministry of Education decile classification system for New Zealand primary schools. Participants from schools with a decile rating of 1-3 were categorised into the 'Low' SES group, while those from schools rated 4-7 and 8-10 were considered 'Middle' and 'High', respectively. Ethical approval for this study was obtained from the Auckland University of Technology Ethics Committee (Appendix D). Written informed consent was provided by each participant and his/her legal guardian.

Physical Activity

Physical activity was measured using sealed multiday memory (MDM) pedometers (Model NL-2000, New Lifestyles Inc., Lee's Summit, MO) over three weekdays and two weekend days. Previous pedometry research has shown that the NL-2000 offers similar accuracy and better precision for measuring steps in children than the widely used Yamax SW-200 pedometer.[64] To assess participant compliance outside of the school environment, parents/caregivers completed a questionnaire the night before the pedometers were collected. Data were excluded if participants did not wear the pedometer for more than one hour on a given day. Daily step counts below 1,000 or above 30,000 were regarded as outliers and were removed.[179]

Weather

Testing took place in Auckland, New Zealand during the winter, spring, and summer months between August and December, 2004. The mean ambient temperatures in Auckland range from 17-23°C in summer to 8-13°C in winter, reflecting its location in a warm-temperate zone (36°51'S, 174°47'E). Access to data from three separate weather stations in the Auckland region was provided by the National Meteorological Service of New Zealand. The weather data ascribed to each participant were obtained from the station closest to their school. Total rainfall (mm), mean ambient temperature (°C), mean wind speed (kph), and the duration of bright sunshine were recorded for the hours between 7am to 7pm on each day of the monitoring period. This 12-hour epoch was chosen as the weather conditions before 7am or after 7pm are unlikely to have an effect children's activity choices.[10] Sunrise and sunset times for every seventh day of the study period were provided by the National Observatory of New Zealand. A sinusoidal curve was fitted to the data ($r^2 = 1.00$) to enable the day length to be estimated for each day of testing.

Statistical Analyses

The effects of the five weather variables on step counts (rounded to the nearest 10 steps to minimise processing requirements) were assessed using the appropriate mixed model (Proc Mixed) in the Statistical Analysis System (Version 9.1, SAS Institute, Cary, NC). The fixed effects were sex × day type, sex × year, sex × SES, and the interactions of each weather variable (day length, rainfall, temperature, wind speed, duration of bright sunshine) with sex and day type. Due to its skewed distribution, rainfall was separated into four groups before analysis: no rainfall (0 mm), light rainfall (0.1-1.0 mm), moderate rainfall (1.1-4.9 mm), and heavy rainfall (> 5 mm). All other weather variables were continuous. The random effects were school variance and between-subject variance (grouped by sex). The aforementioned procedure was repeated twice: once with year (1-2, 3-4, 5-6) and once with SES (high, middle, low) replacing day type in all three-way interactions with sex and weather variables. No clear relationships were observed between residual and predicted scores in the three models, indicating that transformation of step count values was not required.

The effects of unit increases in the five weather variables on step counts (adjusted for variation in all fixed and random effects in the mixed models) were determined separately across all sex, day type, year, and SES groups. To understand the relevance of these results, the standardised effects of meaningful differences in each weather variable were determined using the Cohen technique.[43] The SD values used in the standardization process were calculated for boys and girls separately by combining the between-school SD, the pure between-subject SD, and the weekday and weekend within-subject SDs (scaled by five weekdays to two weekend days) obtained from the mixed model. The effects of a 10ºC increase in mean ambient temperature and a five hour increase in day length were assessed as these differences are typical of the seasonal variation in Auckland. The effects of moderate rainfall (1.1-4.9 mm) and wind (25 kph) were also investigated, as was the effect of a six hour increase in the duration of bright sunshine (half of the 12-hour epoch between 7am and 7pm).

Magnitudes of the standardised effects were interpreted using thresholds of 0.2, 0.6, and 1.2 for small, moderate, and large (respectively). These values were developed to correspond with Cohen's thresholds for correlation coefficients.[43] Inferences about the effects of weather on population step counts were made by expressing uncertainty as 90% confidence limits.[11] An effect was deemed unclear if its CI extended beyond the thresholds defining both positive and negative effects. Otherwise, the magnitude of the effect was reported as the magnitude of the observed value.[11]

Results

Figure 4-1 shows the selected weather variables recorded during the study period (August to December, 2004) for the Auckland region. Day length and mean temperature increased from winter to summer months, but total rainfall, mean wind speed, and duration of bright sunshine did not display seasonal variation.

Table 4-1 gives the mean weekday and weekend steps for the sample (after adjustment for differences in year, SES, and each of the five weather variables), and the adjusted mean step counts (scaled by five weekdays to two weekend days) among year and SES groups. Boys consistently accumulated more steps than girls across all demographic groups and day types. Compared with weekdays, step counts on weekends were considerably lower for both boys and girls. Step counts tended to decrease in girls (but not in boys) with increasing school year. There were no apparent trends in step counts across SES groups for either sex. The standard deviations for the mixed model are also given in Table 4-1: the between-school variation contributed the least to the overall observed variation, whereas the within-subject variation on weekdays and weekend days showed a relatively high degree of spread.

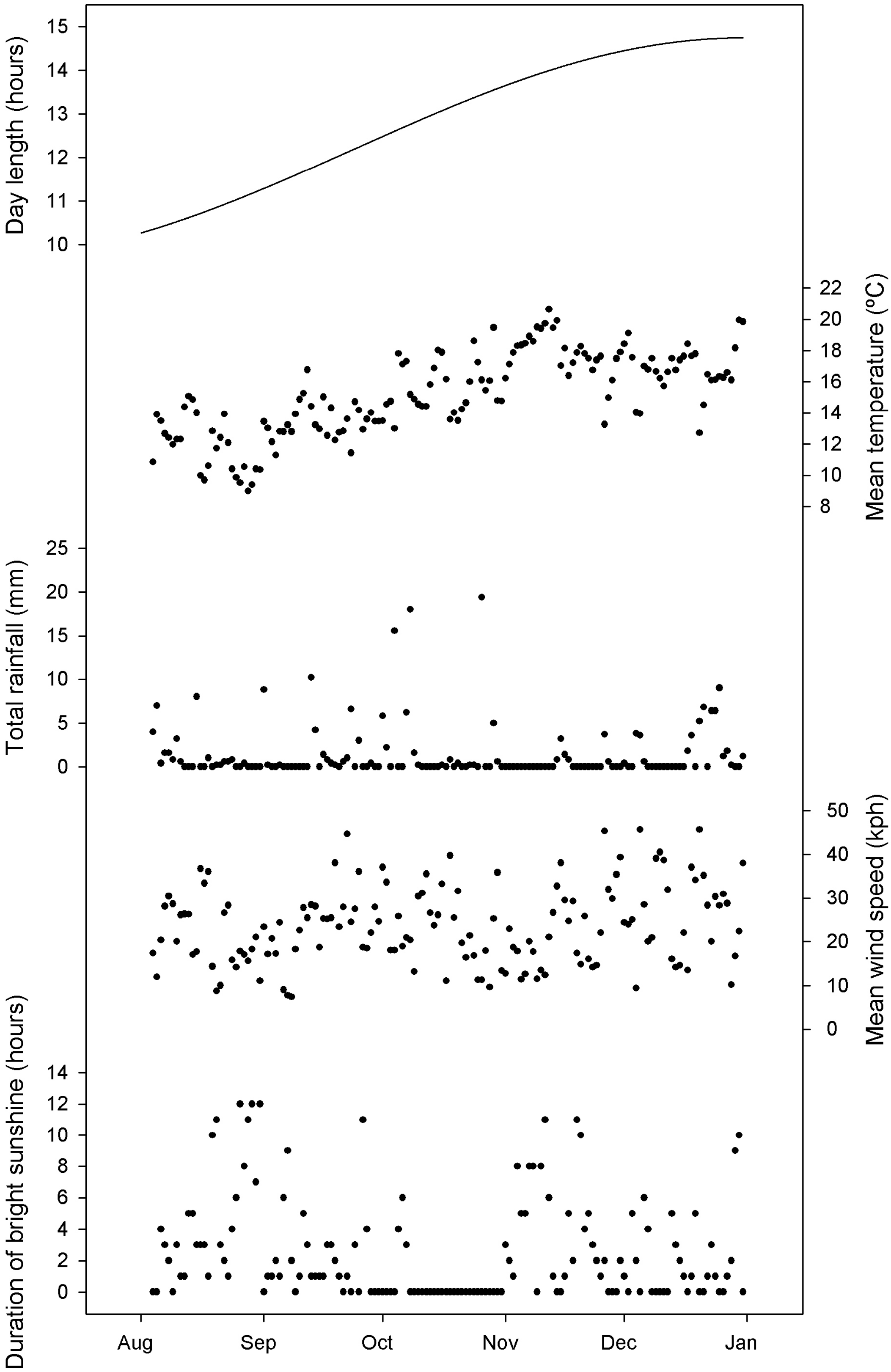

Figure 4-1. Selected weather variables for the months of August to January in Auckland, New Zealand.

Table 4-1. Pedometer-determined physical activity after adjustment for day length, total rainfall, mean ambient temperature, mean wind speed, and duration of bright sunshine (steps.day^{-1}).

	Male (*N* = 536)	**Female (*N* = 579)**
Mean Values		
Weekday	16,130	14,180
Weekend	12,890	11,270
Years 1-2*	15,510	14,050
Years 3-4*	15,110	13,500
Years 5-6*	15,030	12,460
Low SES*	15,060	13,750
Middle SES*	15,030	13,150
High SES*	15,280	13,200
Standard Deviations		
Between-School	690	690
Between-Subject	2,490	2,090
Within-Subject (Weekday)	4,250	3,610
Within-Subject (Weekend)	5,250	4,310
Overall*	5,240	4,410

*Weighted step count (five weekdays/two weekend days).

Data are presented as mean; ± 90% CI.

The effects of each weather variable on male and female step counts are presented in Table 4-2 and Table 4-3, respectively. Overall, there was a positive effect of mean temperature and a negative effect of rainfall. Effects of day length, mean wind, and hours of bright sunshine were more variable. In boys, temperature had the largest effect on the step counts of the low SES group (2.9% per ºC) and on weekend days (2.6% per ºC). Conversely, in girls, temperature had the largest effect on weekday steps counts (1.6% per ºC), with no substantial difference among the SES groups. The percentage difference of a unit increase in rainfall category was greatest for the high SES group in both boys and girls (-8.6% and -7.6%, respectively).

Table 4-2. Differences in steps.day^{-1} for each unit increase in five weather variables (boys).

	Steps per °C	Steps per rainfall category*	Steps per hour day length	Steps per kph of wind speed	Steps per hour of bright sunshine
Day type					
Weekday	170; ± 130	-870; ± 230	-180; ± 330	20; ± 30	0; ± 80
Weekend	340; ± 150	-870; ± 440	-40; ± 370	0; ± 40	60; ± 130
Year*					
1-2	180; ± 180	-640; ± 350	-30; ± 450	20; ± 40	-30; ± 110
3-4	300; ± 180	-1,030; ± 340	-260; ± 420	-10; ± 40	-20; ± 120
5-6	140; ± 170	-1,020; ± 340	-140; ± 440	30; ± 40	60; ± 110
SES*					
Low	440; ± 230	-600; ± 310	-270; ± 530	0; ± 40	10; ± 150
Middle	-100; ± 180	-930; ± 350	-50; ± 500	10; ± 40	-10; ± 150
High	260; ± 170	-1,320; ± 440	-120; ± 610	40; ± 40	-10; ± 90

*Weighted step count (five weekdays/two weekend days).

Data are presented as mean; ± 90% CI.

Table 4-3. Differences in steps.day^{-1} for each unit increase in five weather variables (girls).

	Steps per ºC	Steps per rainfall category*	Steps per hour day length	Steps per kph of wind speed	Steps per hour of bright sunshine
Day type					
Weekday	230; ± 100	-590; ± 180	-150; ± 290	0; ± 30	70; ± 60
Weekend	-30; ± 120	-920; ± 340	180; ± 320	0; ± 30	70; ± 100
Year*					
1-2	70; ± 160	-410; ± 290	110; ± 410	0; ± 40	150; ± 100
3-4	140; ± 140	-960; ± 280	100; ± 360	0; ± 30	20; ± 90
5-6	150; ± 130	-560; ± 250	-170; ± 350	-10; ± 30	60; ± 90
SES*					
Low	140; ± 170	-430; ± 230	100; ± 450	-30; ± 30	240; ± 120
Middle	140; ± 150	-730; ± 290	-220; ± 460	-10; ± 30	10; ± 120
High	20; ± 140	-1,000; ± 360	380; ± 550	60; ± 40	40; ± 80

*Weighted step count (five weekdays/two weekend days).

Data are presented as mean; ± 90% CI.

Table 4-4. Standardised effects of increases in five weather categories on pedometer-determined physical activity (boys).

	Mean temperature (+10ºC)	**Rainfall (+2 categories)**	**Day length (+5 hr)**	**Mean wind speed (+25 kph)**	**Duration of bright sunshine (+6 hr)**
Day type					
Weekday	0.32; ± 0.25 small	-0.33; ± 0.09 small	-0.17; ± 0.31 trivial	0.10; ± 0.14 trivial	0.00; ± 0.09 trivial
Weekend	0.65; ± 0.29 moderate	-0.33; ± 0.17 small	-0.04; ± 0.35 unclear	0.00; ± 0.19 trivial	0.07; ± 0.15 trivial
Year*					
1-2	0.34; ± 0.34 small	-0.24; ± 0.13 small	-0.03; ± 0.43 unclear	0.10; ± 0.19 trivial	-0.03; ± 0.13 trivial
3-4	0.57; ± 0.34 small	-0.39; ± 0.13 small	-0.25; ± 0.40 small	-0.05; ± 0.19 trivial	-0.02; ± 0.14 trivial
5-6	0.27; ± 0.32 small	-0.39; ± 0.13 small	-0.13; ± 0.42 unclear	0.14; ± 0.19 trivial	0.07; ± 0.13 trivial
SES*					
Low	0.84; ± 0.44 moderate	-0.23; ± 0.12 small	-0.26; ± 0.51 unclear	0.00; ± 0.19 trivial	0.01; ± 0.17 trivial
Middle	-0.19; ± 0.34 trivial	-0.35; ± 0.13 small	-0.05; ± 0.48 unclear	0.05; ± 0.19 trivial	-0.01; ± 0.17 trivial
High	0.50; ± 0.32 small	-0.50; ± 0.17 small	-0.11; ± 0.58 unclear	0.19; ± 0.19 trivial	-0.01; ± 0.10 trivial

*Weighted step count (five weekdays/two weekend days).

Data are presented as mean; ± 90% CI.

Table 4-5. Standardised effects of increases in five weather categories on pedometer-determined physical activity (girls).

	Mean temperature (+10ºC)	**Rain (+2 categories)**	**Day length (+5 hr)**	**Mean wind speed (+25 kph)**	**Duration of bright sunshine (+6 hr)**
Day type					
Weekday	0.52; ± 0.23 small	-0.27; ± 0.08 small	-0.17; ± 0.33 trivial	0.00; ± 0.17 trivial	0.10; ± 0.08 trivial
Weekend	-0.07; ± 0.27 unclear	-0.42; ± 0.15 small	0.20; ± 0.36 small	0.00; ± 0.17 trivial	0.10; ± 0.14 trivial
Year*					
1-2	0.16; ± 0.36 unclear	-0.19; ± 0.13 trivial	0.12; ± 0.46 unclear	0.00; ± 0.23 unclear	0.20; ± 0.14 small
3-4	0.32; ± 0.32 small	-0.44; ± 0.13 small	0.11; ± 0.33 unclear	0.00; ± 0.17 trivial	0.03; ± 0.12 trivial
5-6	0.34; ± 0.29 small	-0.25; ± 0.11 small	-0.19; ± 0.40 unclear	-0.06; ± 0.17 trivial	0.08; ± 0.12 trivial
SES*					
Low	0.32; ± 0.39 small	-0.20; ± 0.10 small	0.11; ± 0.51 unclear	-0.17; ± 0.17 trivial	0.33; ± 0.16 small
Middle	0.32; ± 0.34 small	-0.33; ± 0.13 small	-0.25; ± 0.52 unclear	-0.06; ± 0.17 trivial	0.01; ± 0.16 trivial
High	0.05; ± 0.32 unclear	-0.45; ± 0.16 small	0.43; ± 0.62 unclear	0.34; ± 0.23 small	0.05; ± 0.11 trivial

*Weighted step count (five weekdays/two weekend days).

Data are presented as mean; ± 90% CI.

Table 4-4 and Table 4-5 show the standardised effect sizes for selected changes to each of the five weather variables. In boys, a 10ºC increase in mean temperature had a larger effect on weekend step counts (moderate) than on weekday step counts (small). By contrast, the equivalent increase in mean temperature had a trivial effect on weekend step counts and a small effect on weekday step counts in girls. Corresponding effect magnitudes across year and SES groups were also variable, ranging from trivial to moderate. The negative effect of moderate rainfall on step counts was similar across day types and year groups for both sexes. However, there was a trend for the effect of rainfall to increase with SES. Effects of the selected changes to day length, wind speed, and hours of bright sunshine on step counts were largely trivial or unclear.

Discussion

It is generally accepted that inclement weather can discourage physical activity participation in young people.[10,19] While the weather itself cannot be controlled, an understanding of the conditions that present the greatest barriers to activity in children is useful for informing the delivery of alternative options to outdoor play. This study represents the first investigation of the associations between meteorological factors and daily physical activity levels in a paediatric sample. Our results indicate that a decrease in mean ambient temperature and an increase in total rainfall can have a negative impact on step counts, regardless of day length, mean wind speed, or duration of bright sunshine. Thus, studies comparing physical activity levels across different locations or time periods may need to account for the confounding effect of temperature or rainfall variation.

The magnitude of the effect of temperature on step counts was dependent on sex, day type, year level, and SES. For example, temperature had moderate effect on weekend activity in boys, but an unclear effect on weekend activity in girls. While the reasons for this sex-related variation are uncertain, it is possible that outdoor activities influenced by ambient temperature are more popular in boys than in girls. Expressed as a change in daily steps, the seasonal variation in temperature from winter to summer months corresponded to 1,700 (10.5%) more weekday steps and 3,400 (26.4%) more weekend steps for boys, and 2,300 (16.2%) more weekday steps for girls. These percentage increases are considerably greater than the 2.9% increase in daily steps observed for a 10ºC rise in temperature in Canadian adults,[36] but similar to the 13.7% increase in steps.day^{-1} between 0ºC and 10ºC in Japanese adults.[212] As neither study quantified the difference between weekday and weekend step counts, it is unclear whether the effect of mean ambient temperature on adult activity is dependent on day type. In the present study, differences in the association between temperature and step counts were also observed across SES groups, with the Middle SES group in boys and the High SES group in girls showing trivial and unclear temperature effects, respectively. The impact of weather on activity is clearly a complex issue that is contingent on interactions between several demographic variables.

Although our results indicate that temperature changes between winter and summer months can have meaningful effects on children's daily activity in a temperate climate, it is also important to consider the potential effects of day-to-day variation in temperature. The practical relevance of temperature effects can be evaluated by interpreting the standardised effect size relative to the maximum temperature variation in an average week (3.3ºC in the present study). While the mean effect of a 10°C (seasonal) increase in mean ambient temperature on weekday steps was small for both boys and girls (0.32 and 0.52, respectively), the mean effect of a 3.3ºC increase would be trivial (0.11 and 0.17). In fact, small effects of day-to-day variation in temperature were only observed for weekend steps in all boys, and for overall scaled step counts in Low SES boys. This suggests that the typical temperature variation within a given week in the Auckland region is only sufficient to influence activity choices in certain subpopulations of children. However, individuals exposed to climates with greater day-to-day variation in mean temperature are more likely to exhibit weather-related activity patterns during the week.

It is interesting to note that the positive relationships between ambient temperature and step counts were independent of day length. In fact, the effects of day length on step counts after adjustment for mean ambient temperature were largely unclear. This suggests that the peak in physical activity participation commonly observed during the summer months[10,35,53,145,223,230,233] may reflect ambient temperatures that encourage outdoor pursuits rather than the number of daylight hours. Previous research in adults has reached similar conclusions: Chan *et al.*[36] reported that mean ambient temperature had a significant effect on activity independent of the month of the year, while Togo *et al.*[212] found that temperature had a stronger association with activity than day length. The decrease in physical activity participation associated with colder weather may contribute to the relatively high prevalence of cardiovascular events observed during winter months.[166] Thus, developing and promoting physical activity opportunities during cold periods may be a worthwhile strategy for people of all ages.

The effects of precipitation on daily activity showed greater consistency than the effects of mean ambient temperature. In accordance with previous research in adults,[36,212] moderate rainfall (two categories higher than no rain) had a small negative effect on weekday and weekend activity for both sexes. This translates to a 1,740 (10.8%) and 1,180 (8.3%) decrease in steps.day^{-1} for boys and girls (respectively) on weekdays, and a 1,740 (13.5%) and 1,840 (16.3%) decrease in steps.day^{-1} on weekends. Although effects were similar across year groups, the impact of rainfall on daily activity increased with SES. It is possible that children from a low socioeconomic background participate in fewer organised sports (which are subject to rain cancellations) and/or place greater reliance on active transport than High SES children. Difference ethnic or cultural norms linked with SES may also contribute to the association between precipitation and physical activity. In any case, offering alternative activities to counteract the reduction in children's activity during moderate to heavy rainfall is clearly a key priority for lifestyle interventions.

Our analyses for the effects of wind speed between the hours of 7am and 7pm indicate that the occurrence of windy conditions does not influence physical activity behaviour in children living in Auckland. This is in contrast to recent findings in Canadian adults, where a 2 to 5% decrease in activity was associated with maximum wind speeds greater than 20 kph.[36] Given that the peak wind speed in the Canadian study was estimated over a 24 hour period, it is likely that the decline in activity associated with high winds would be even greater if the wind conditions had been determined for daylight hours only. Although similar research in Japanese adults found no correlation between mean wind speed and activity,[212] the wind speeds assessed in the latter study were relatively low (< 20 kph). Nevertheless, we observed predominantly trivial effects even at a mean wind speed of 25 kph. The differences observed between studies may reflect a tendency for children to be less discouraged by moderate to high winds than adults. Alternatively, inherent differences in the impact of windy conditions on physical activity behaviours may exist between countries due to population-specific social norms. Comparing the effects of wind on activity in children and adults from the same population would help to clarify this issue. Another meteorological factor that may require further study is the duration of bright sunshine: this variable also had little impact on activity in the present sample but a significant effect in previous research in adults.[212]

Overall, mean ambient temperature and rainfall appear to be the most important weather determinants of children's physical activity participation in temperate climates. However, devising appealing opportunities for children to be physically active on cold and/or rainy days can be challenging. Schools have a significant role to play by offering indoor activity when children are not permitted to play outside (e.g., during wet lunchtimes). Out of school, the availability of community facilities for indoor recreational activity (e.g., gymnasiums, swimming pools) is an important factor. Another potential strategy is to ensure parents are able to provide children with active options within the home environment. Promoting the use of suitable clothing to allow walking in all weather conditions may worthwhile in this regard. Future research is required to determine the most effective approaches for counteracting the detrimental effect of cold temperatures and rainfall on children's activity.

A potential limitation of this study is that weather data were collected at fixed stations ranging from 3 to 15 km away from participating schools. Thus, localised weather conditions experienced by some children may not have been evident in our data. In addition, the results presented in this study are applicable children living in temperate climates only. The effects of meteorological variables common in other climates (e.g., snowfall, extreme temperatures) on physical activity in children remain uncertain. Finally, pedometers provide a measure of total daily physical activity, and thus do not give an indication of the specific weather-related changes in activity patterns that may occur within a given day. The use of measurement techniques that are able to record the frequency and intensity of activity (e.g., accelerometers, heart rate monitors) will provide further insight into children's short-term responses to variable weather conditions.

In summary, this study provides the first data describing the associations between weather conditions and daily physical activity levels in children. Our results indicate that moderate rainfall and a reduction in mean ambient temperature can have small to moderate negative effects on children's activity in a temperate climate. Furthermore, interactions among weather conditions, day type, and demographic factors suggest that the impact of weather on children's physical activity during weekdays and weekends is not consistent for all population subgroups. Nevertheless, the development of attractive activity options for cold and/or rainy days is likely to have beneficial effects on children's physical activity levels.

CHAPTER 5

PEDOMETER STEPS AND OBESITY IN CHILDREN

Preface

This chapter represents the first of the two major sections in this thesis. The preceding chapters established the validity of pedometers for assessing physical activity in children, and examined associations between weather and activity in children recruited for the main cross-sectional study. However, the primary purpose of this thesis was to investigate the relationship between physical activity and excess body fatness in children. Given the recent popularity of pedometers in health promotion, and the increasing prevalence of childhood obesity around the world, an understanding of the interaction between step counts and body composition in children is essential. Thus, this chapter explores the associations between daily steps and three common measures of body composition: BMI, WC, and %BF. The paper resulting from this chapter was published in the August 2006 issue of *Medicine and Science in Sports and Exercise* (Appendix A).

Abstract

Objectives: The objectives of this study were to examine current levels of pedometer-determined physical activity in a multiethnic sample of New Zealand children, and to investigate associations among weekday and weekend step counts, body mass index (BMI), waist circumference (WC), and percentage body fat (%BF).

Methods: A total of 1,115 children (536 male, 579 female) aged 5-12 years wore sealed multiday memory pedometers for three weekdays and two weekend days. The ethnic composition of the sample was 49.2% European, 30.0% Polynesian, and 16.5% Asian, with 4.3% from other ethnicities. BMI was determined from height and weight, and %BF was measured using hand-to-foot bioelectrical impedance analysis. Participants were classified as normal weight, overweight, or obese using international BMI cut-off points,[44] and into normal or central fat distribution groups using national WC standards.[208] The 90th percentile of %BF for each age and sex subgroup was used to identify normal and high body fatness.

Results: Mean step counts for this sample were 16,133 ± 3,864 (boys) and 14,124 ± 3,286 (girls) on weekdays, and 12,702 ± 5,048 (boys) and 11,158 ± 4,309 (girls) on weekends. Significant differences in step counts were observed between weekdays and weekends, boys and girls, and among age, ethnic, and socioeconomic groups. Analysis of variance revealed stronger associations between step counts and %BF category than between step counts and BMI or WC groups.

Conclusions: This study provides evidence of a link between daily step counts and body fatness in children. Our results also suggest that the promotion of physical activity during the weekend is a key priority for young New Zealanders.

Introduction

The escalation of obesity into a worldwide epidemic raises the prospect of serious health and economic consequences for many countries. Although the prevalence of obesity continues to increase in people of all ages,[255] childhood obesity undoubtedly presents the greatest long-term concerns from a population health perspective. In the USA, obesity in 6-11-year-old children (defined as a body mass index [BMI] at or above the 95th percentile of national growth charts) rose from 6.5% in 1976-1980, to 11.3% in 1988-1994, to 15.3% in 1999-2000.[162] These substantial increases in obesity are not exclusive to young Americans – similar patterns have been observed in other countries, including Australia,[18] France,[239] and the UK.[39] Using international age- and sex-specific BMI cut-off points,[44] a national survey conducted in 2002 found that 9.8% of New Zealand children were classified as obese.[152] Furthermore, a recent longitudinal study found that the risk of obesity in 2000 was 3.8 times greater than the risk in 1989,[227] suggesting that the prevalence of childhood obesity in New Zealand is following overseas trends.

Such findings have triggered an upsurge in the promotion of physical activity among young people as a long-term solution to the obesity epidemic. This has coincided with a widespread increase in the availability of step-counting pedometers for monitoring daily activity levels. For researchers, pedometers provide an objective, cost-effective assessment of physical activity that can be easily compared among different time periods, age groups, and/or locations.[198] Pedometers are especially useful for studies of paediatric populations, where the inability of younger children to accurately recall their activity behaviour can reduce the efficacy of questionnaires and interviews.[184] Although pedometers are unable to detect physical activity intensity, duration, or frequency, there are clear benefits to recording a measurement unit that has direct applications to health promotion. Increasing the number of steps.day^{-1} encourages the accumulation of physical activity in people of all ages and physical abilities, and is less complicated than alternative recommendations based on physical activity intensity and duration. Pedometer-based interventions have already proven effective for increasing physical activity in adults[47,128] and adolescent girls.[190]

Numerous descriptive studies have implemented pedometers to assess weekday physical activity in children,[138,181,237] yet comparatively few have obtained separate data representing weekend days. The number of steps taken by children on the weekends is of particular interest given the current evidence that young people are less active when outside the school environment.[81,106] In order to discern step counts for individual days, conventional pedometers (such as the Yamax Digiwalker series) require researchers to visit participants at school each morning to record data from the previous day. Naturally, this procedure becomes more difficult during the weekend when children are at home. It is possible to obtain weekend data by relying on self-reported step counts, however the prevalence of age-related recall bias and/or deliberate misrepresentation appears high in young people.[215] Alternatively, the multiday memory (MDM) pedometer features an internal clock that automatically categorises data according to the day of the week, enabling researchers to collect both weekday and weekend data while restricting participant contact to before and after the test period.

Although daily step count targets appear to be a promising approach for increasing population physical activity and thus lowering the risk of obesity, there is limited information describing the association between steps.day^{-1} and body composition in children. In the only large-scale study of activity and body size in young people, Vincent *et al*.[237] found few significant relationships between weekday steps and BMI. The latter result is surprising given the growing body of longitudinal evidence supporting the role of physical activity in the prevention of childhood obesity.[66,154] One possibility is that pedometers do not provide a suitably accurate estimate of physical activity to enable the detection of a significant association with body size. This is unlikely, however, given that previous research has established pedometers as a valid measure of activity in children.[198] An alternative explanation is that BMI, as a weight-based index, is a simplistic indicator of adiposity. It is noteworthy that physical activity lowers the risk of obesity-related complications by reducing the accretion of body fat rather than decreasing body weight. The natural increases in height and weight that occur during growth may also complicate the relationship between BMI and physical activity. Indeed, several studies have observed stronger associations between activity and body fat than between activity and BMI.[5,154] Even waist circumference (WC), a proxy measure of central fat accumulation, appears more closely related to activity levels in young people than BMI.[118] We suggest that obtaining more direct measures of body fatness will increase the probability of detecting significant associations between pedometer steps and obesity in children.

It is clear that the association between steps.day^{-1} and body composition in paediatric populations needs further clarification. Thus, the primary purpose of this study was to investigate pedometer steps in relation to BMI, WC, and percentage body fat (%BF) in a large sample of New Zealand children. A secondary objective was to compare differences in activity between weekdays and weekends, and among European, Polynesian, and Asian children.

Methods

Participants

A total of 2,000 children (1,000 male, 1,000 female) aged 5-12 years were randomly selected from 27 primary (elementary) schools in Auckland, New Zealand. Participating schools were purposively sampled to replicate the overall geographic and socioeconomic distribution of primary schools in the Auckland region (Appendix L). Consent was obtained for 1,251 of the 2,000 children selected (68.3%), and 1,229 children (603 male, 626 female) eventually took part in the study. Of this initial group, 29 participants (2.4%) either lost or damaged their pedometer during testing. A further 85 (6.9%) provided incomplete data and were excluded from analysis, resulting in a final sample size of 1,115 (536 male, 579 female). The ethnic composition of this sample was 549 European children (49.2%), 334 Polynesian children (30.0%), 184 Asian children (16.5%), and 48 children from other ethnic groups (4.3%). The Polynesian ethnic group was comprised of Pacific Island (56.0%) and Maori (44.0%) children, and the Asian ethnic group included Indian (38.0%), Chinese (22.3%), Korean (13.0%), Filipino (9.8%), Sri Lankan (4.3%), and Other Asian (12.6%) children.

Socioeconomic status (SES) was estimated using the Ministry of Education decile classification system for New Zealand primary schools. For the purposes of this study, participants from schools with a decile rating between 1-3 were categorised into the 'Low' SES group, while those from schools rated 4-7 or 8-10 were considered 'Middle' or 'High', respectively. Although this proxy measure of SES may not accurately classify all individuals, it negated the potential parent/caregiver burden associated with a socioeconomic questionnaire. Ethical approval for this study was obtained from the Auckland University of Technology Ethics Committee (Appendix D). Written informed consent was provided by each participant and his/her legal guardian.

Physical Activity

The New Lifestyles NL-2000 (Lee's Summit, MO) MDM pedometer was used to monitor daily physical activity. Previous research has shown that the NL-2000 offers a degree of accuracy comparable to the widely used Yamax Digiwalker series while providing the added benefits of a MDM function.[189] Each NL-2000 pedometer was checked for defects prior to use in the study by observing the recorded step count after walking 100 paces. Instrumental error did not exceed 3% in any of the pedometers. Testing took place during the spring months between August and December. Each participant was given a short explanation about the study before receiving a demonstration about how to attach a pre-sealed pedometer to the waistline. Participants were then asked to wear the pedometer all day for seven consecutive days (except when sleeping or swimming). On the seventh day of monitoring, researchers visited the participants to collect pedometers and record the number of steps taken on each of the testing days. Pedometers were not available to the participants on the morning of the first testing day or the evening of the last testing day, resulting in a maximum of five full days of data (three weekdays and two weekend days). Previous research has suggested that 4-5 days of monitoring is sufficient to obtain a reliable ($ICC > 0.80$) estimate of physical activity in children.[218]

To assess participant compliance outside of the school environment, parents/caregivers completed a questionnaire the night before the pedometers were collected (Appendix I). This alerted researchers to times during the monitoring period that parents/caregivers were aware their children had removed the pedometer. Although this method is less effective for detecting non-compliance when parents/caregivers are not present, the low reliability of self-report techniques in children[184] precluded their use in this study. Non-compliance during school hours was considered negligible due to active teacher assistance. At present, a standard non-compliance time period above which pedometer data are discarded has yet to be established. Data treatment procedures used in previous studies range from the inclusion of all daily pedometer data regardless of participant compliance[215] to the exclusion of data from participants who removed their pedometer for more than one hour on any given day.[248] Although the latter criterion results in a greater number of exclusions, it is likely to provide the most accurate estimates of daily steps. Thus, children in the present study who removed their pedometer for more than one hour on any given day had the steps accumulated on that day omitted from analysis. Participants were excluded from the study if more than one weekday and one weekend were lost due to incomplete data.

Nevertheless, the possibility that non-compliant individuals were overlooked due to inaccurate parent/caregiver questionnaires cannot be ruled out. Of particular concern is the potential for abnormally low or high step counts to be retained in the dataset. To date, there is limited information concerning the treatment of extreme values in pedometry research. The only existing standards for children were developed by Rowe *et al.*[179] using a combination of percentile analysis and previous experience. It was proposed that daily step counts below 1,000 or above 30,000 were unlikely to be valid and should be regarded as outliers. Five participants (0.4%) from the present study were excluded by these criteria.

Body Composition

The standing height of each participant was measured to the nearest millimetre with a portable stadiometer (Design No. 1013522, Surgical and Medical Products, Seven Hills, Australia), and weight was measured to the nearest 0.1 kg on a digital scale (Model Seca 770, Seca, Hamburg, Germany). BMI was then calculated as weight (kg) divided by squared height (m^2). During data analysis, participants were classified as normal weight, overweight, or obese using international age- and sex-specific BMI cut-off points.[44] In addition, WC measurements were made at the highest point of the iliac crest at minimal respiration. Children with a central pattern of fat distribution were identified using the WC cut-offs developed for New Zealand children by Taylor *et al.*[208]

Body fat measurements were obtained using hand-to-foot bioelectrical impedance analysis (BIA). Resistance (R) was measured at 50 kHz using a bioimpedance analyser

(Model BIM4, Impedimed, Capalaba, Australia) with a tetrapolar arrangement of self-adhesive electrodes (Red Dot 2330, 3M Healthcare, St Paul, MN, USA). After swabbing the skin on the right hand and foot with alcohol, source electrodes were placed on the dorsal surface of the foot over the distal portion of the second metatarsal, and on the hand on the distal portion of the second metacarpal. Sensing electrodes were placed at the anterior ankle between the tibial and the fibular malleoli, and at the posterior wrist between the styloid processes of the radius and ulna. Testing was initiated after the participants emptied their bladder, and had been lying supine with their arms and legs abducted for at least 5 min. Testing was completed when repeated measurements of R were within 1 Ω of each other. Fat-free mass (FFM) was then calculated from R, height, and weight using a prediction equation previously validated with deuterium dilution ($r^2 = 0.96$, SEE = 2.44 kg) in New Zealand children.[182] To ensure consistency between samples, preparation procedures in the present study were identical to those implemented by Rush *et al*.[182] Fat-mass (FM) was derived as the difference between FFM and body weight. Percentage body fat was calculated as 100 × FM/weight. Children above the 90th percentile of %BF for each age- and sex-specific group in the sample were classified as having excessive body fatness. Unlike BMI, there are no generally accepted definitions of overweight or obesity in children based on %BF. Given that approximately 10% of New Zealand children are classified as obese using international BMI thresholds,[152] the 90th percentile of %BF was chosen as the cut-off point for identifying excessively high levels of body fatness in this sample.

Statistical Analyses

Data were analysed using SPSS version 12.0.1 for Windows (SPSS Inc., Chicago, IL). Differences in participant characteristics (age, height, weight, BMI, WC, and %BF) between sexes and among ethnic groups were assessed by two-way ANOVA and significant associations were examined by pairwise comparisons using *t*-tests. One-way ANOVA and Bonferroni *post hoc* tests were used to determine where significant differences in step counts existed among ethnic, age, socioeconomic, BMI, WC, and %BF groups. Associations among weekday and weekend step counts, sex, ethnicity, and %BF category were assessed using a factorial repeated measures ANCOVA (Sex by Ethnicity by %BF by Day) with age and SES as covariates. A P value less than 0.05 was used to indicate statistical significance.

Results

The physical characteristics of each ethnic group in this study are presented in Table 5-1. Although there were no significant effects of sex on age, height, weight, BMI, or WC, significant differences in %BF were detected between boys and girls within each ethnic group (excluding Other Ethnicities). Furthermore, Polynesian children were heavier than European and Asian children, and had a greater BMI and WC. Ethnic differences in %BF were also observed, with Polynesian and Asian boys carrying significantly more body fat than their European counterparts. Similar %BF trends were found in girls, although the difference between European and Asian groups was not significant ($P = 0.108$).

Table 5-2 shows the mean weekday and weekend step counts for the study sample grouped according to sex, ethnicity, age, socioeconomic status, BMI, WC, and %BF. Mean weekday steps were consistently higher and had smaller standard deviations than mean weekend steps across all subgroups. Preliminary analysis revealed significant differences in weekday steps between boys and girls and among the three major ethnic groupings, with Polynesian children the most active and Asian children the least active during weekdays. Weekend activity showed similar patterns between sexes and among ethnicities, although European children averaged the highest weekend step count. Weekend activity decreased with age and increased with socioeconomic status, trends that were not observed for weekday activity.

Table 5-1. Participant characteristics for main study sample.

	European		Polynesian		Asian		Other Ethnicities	
	M (*N* = 266)	F (*N* = 283)	M (*N* = 159)	F (*N* = 175)	M (*N* = 92)	F (*N* = 92)	M (*N* = 19)	F (*N* = 29)
Age (years)	8.2 ± 1.7	8.4 ± 1.7	8.5 ± 1.8	8.5 ± 1.8	8.7 ± 1.6	8.7 ± 1.7	8.8 ± 1.8	8.6 ± 1.8
Height (cm)	131.0 ± 12.0	130.9 ± 11.8	133.9 ± 12.6	133.8 ± 13.2	130.9 ± 9.8	130.7 ± 12.3	133.4 ± 10.8	130.6 ± 9.8
Weight (kg)	29.9 ± 8.6[b]	30.4 ± 9.7[b]	36.4 ± 13.5	36.4 ± 14.4	30.3 ± 8.2[b]	29.7 ± 9.3[b]	30.6 ± 7.8	29.5 ± 7.8[a]
BMI (kg·m^{-2})	17.1 ± 2.4[b]	17.3 ± 2.8[b]	19.7 ± 4.5	19.6 ± 4.5	17.4 ± 2.8[b]	17.0 ± 2.9[b]	17.0 ± 2.6[a]	17.0 ± 2.6[a]
WC (cm)	59.7 ± 7.8[b]	59.9 ± 7.9[b]	65.3 ± 11.6	64.4 ± 11.7	60.9 ± 8.5[b]	59.0 ± 8.4[b]	60.5 ± 6.5	58.0 ± 6.9[b]
Body fat (%)	17.5 ± 6.0[bcd]	21.2 ± 6.4[a]	21.0 ± 7.7[d]	23.3 ± 7.2	20.3 ± 6.9[d]	23.2 ± 7.7	20.2 ± 7.2	22.7 ± 6.1

Data are presented as mean ± SD. BMI, body mass index; WC, waist circumference; M, male; F, female.
[a]Significantly different from Polynesian of same sex ($P < 0.05$).
[b]Significantly different from Polynesian of same sex ($P < 0.005$).
[c]Significantly different from Asian of same sex ($P < 0.005$).
[d]Significantly different from female of same ethnicity ($P < 0.005$).

Table 5-2. Pedometer-determined physical activity in main study sample (steps.day^{-1}).

	Weekday Steps		Weekend Steps	
	N	**Mean ± SD**	***N***	**Mean ± SD**
Total	1074	15,085 ± 3,711	1011	11,886 ± 4,733
Sex[ab]				
Male	514	16,132 ± 3,864	477	12,702 ± 5,048
Female	560	14,124 ± 3,286	534	11,158 ± 4,309
Ethnicity[ab]				
European	526	15,072 ± 3,459	504	12,302 ± 4,591
Polynesian	322	15,747 ± 4,185	291	11,836 ± 5,257
Asian	180	14,134 ± 3,570	172	10,925 ± 4,221
Other	46	14,328 ± 2,412	44	11,214 ± 4,016
Age (years)[b]				
5-6	183	15,284 ± 3,311	164	12,948 ± 4,551
7-8	360	15,201 ± 3,404	337	12,612 ± 4,855
9-10	363	15,003 ± 4,019	352	11,250 ± 4,525
11-12	168	14,801 ± 4,055	158	10,656 ± 4,653
Socioeconomic status[b]				
Low	372	15,264 ± 3,965	345	11,004 ± 4,792
Middle	313	14,780 ± 3,406	292	12,112 ± 4,660
High	389	15,160 ± 3,690	374	12,525 ± 4,624
BMI (kg·m^{-2})[b]				
Normal weight	789	15,151 ± 3,554	746	12,185 ± 4,713
Overweight	188	15,098 ± 4,169	172	11,139 ± 4,450
Obese	97	14,524 ± 4,002	93	10,872 ± 5,142
Waist circumference[cd]				
Normal fat distribution	838	15,190 ± 3,612	790	12,101 ± 4,701
Central fat distribution	231	14,638 ± 4,001	215	11,152 ± 4,762
Percentage body fat[ad]				
< 90th percentile	961	15,235 ± 3,693	906	12,028 ± 4,739
≥ 90th percentile	104	13,750 ± 3,652	97	10,693 ± 4,629

[a]Significantly different for weekday steps ($P < 0.005$).
[b]Significantly different for weekend steps ($P < 0.005$).
[c]Significantly different for weekday steps ($P < 0.05$).
[d]Significantly different for weekend steps ($P < 0.05$).

Table 5-3. Results of a factorial repeated measures ANCOVA (Sex by Ethnicity by %BF by Day) corrected for age and SES.

Source	***F***	***P***
Within Subjects		
Day	18.233	0.000[b]
Day x Age	16.727	0.000[b]
Day x SES	9.850	0.002[b]
Day x Sex	4.173	0.041[a]
Day x Ethnicity	0.087	0.917
Day x %BF	0.513	0.474
Day x Sex x Ethnicity	0.142	0.867
Day x Sex x %BF	0.023	0.879
Day x Ethnicity x %BF	1.138	0.321
Day x Sex x Ethnicity x %BF	1.116	0.328
Between Subjects		
Age	16.162	0.000[b]
SES	8.383	0.004[b]
Sex	13.428	0.000[b]
Ethnicity	5.812	0.003[b]
%BF	13.523	0.000[b]
Sex x Ethnicity	0.457	0.633
Sex x %BF	1.765	0.184
Ethnicity x %BF	0.570	0.566
Sex x Ethnicity x %BF	0.217	0.805

[a]Significant ($P < 0.05$) level.
[b]Significant ($P < 0.005$) level.

The relationships between mean step counts and each of the three body composition variables included in this study were analysed separately. First, international BMI cut-off points for childhood overweight and obesity[44] were applied to the sample. Overall, 73.5% of participants were classified as 'normal' weight, with 17.3% overweight and a further 9.2% obese. Analysis of variance showed a significant difference in weekend but not weekday ($P = 0.291$) step counts among the three BMI categories (Table 5-2). Participants were then grouped according to the WC standards proposed by Taylor *et al*.[208] Compared with BMI, differences in activity between children with normal fat distribution (78.4%) and those with central fat distribution (21.6%) were larger for weekdays and similar for weekends. Finally, the greatest differences in steps.day^{-1} were found when participants were categorised into either normal (< 90th percentile) or high (> 90th percentile) %BF groups. Both weekday and weekend activity was significantly lower for children with high %BF (9.5%) when compared to those with normal %BF levels (90.5%).

To investigate the interaction among the key factors associated with activity in this sample, sex (male and female), ethnicity (European, Polynesian, and Asian), %BF (normal %BF and high %BF), and day (weekday and weekend) were entered into a 2 x 3 x 2 x 2 factorial repeated measures ANCOVA (Sex by Ethnicity by %BF by Day) with age and SES as covariates (Table 5-3). Mean step counts differed significantly between weekdays and weekends, with significant interactions between day and age, day and socioeconomic status, and day and sex. No significant interactions existed between day and ethnicity, day and %BF, or among any of the higher level combinations. This indicates that the significant decrease in activity observed on weekend days is affected by age, socioeconomic status, and sex, but not by ethnicity or %BF category. Analysis of the between subject variance revealed significant associations between overall mean step count and both age and SES. Significant differences between boys and girls, among ethnicities, and between %BF groups were also detected. The latter finding, in addition to the non-significance of the interaction between day and %BF, shows that a high level of %BF (> 90th percentile) is associated with a significantly lower number of daily steps on both weekdays and weekends. Furthermore, the non-significant interactions among sex, ethnicity, and %BF indicate that the negative association between %BF status and daily steps is similar for boys and girls from all ethnic groups.

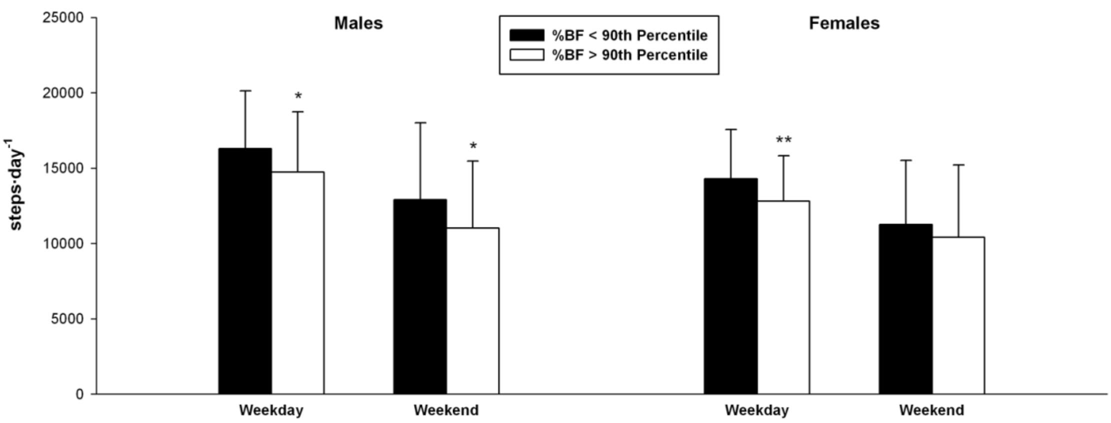

Figure 5-1. Pedometer-determined physical activity during weekdays and weekends grouped by sex and %BF.

Data are presented as mean ± SD.
*Significant ($P < 0.05$) level.
**Significant ($P < 0.005$) level.

Figure 5-1 shows the differences in weekday and weekend step counts between %BF groups for all ethnicities. On average, boys with normal %BF levels accumulated 1,554 more steps each weekday and 1,893 more steps each weekend than boys with high %BF. Girls with normal %BF levels achieved 1,480 more steps each weekday but only 844 more steps each weekend when compared to those in the high %BF group. The Cohen effect size statistics associated with these differences were 0.40 for boys and 0.47 for girls on weekdays, and 0.40 for boys and 0.19 for girls on weekends. This implies that %BF status had a small association with mean weekday and weekend steps in boys, a slightly larger association with mean weekday steps in girls, and a trivial association with mean weekend steps in girls.

Discussion

The results presented in this study represent the only step count data available for young New Zealanders, and have enabled us to observe the physical activity patterns of New Zealand children from an international perspective for the first time. Previous research from a large three-country sample found that Swedish children were the most active on weekdays (15,673-18,346 steps.day^{-1} for boys, and 12,041-14,825 steps.day^{-1} for girls), followed by Australian children (13,864-15,023 and 11,221-12,322 steps.day^{-1}), and then American children (12,554-13,872 and 10,661-11,383 steps.day^{-1}).[237] Comparing these data with findings from the present study suggest that New Zealand children are relatively active, with boys averaging 16,133 steps and girls averaging 14,124 steps each weekday. It should be noted, however, that such comparisons of physical activity levels do not necessarily reflect the overall variation between countries as neither dataset is representative. The potential measurement error between different brands of pedometer may be another confounding factor.[130]

The mean step counts recorded on weekends were significantly lower than on weekdays in our sample (boys, 12,702; girls, 11,158), with the extent of the decrease dependent on participant age, sex, and socioeconomic status. This may be a result of greater opportunities to participate in active play, sport, or physical education programs when at school, and suggests that the promotion of activity during out-of-school hours is a priority. However, previous comparisons of weekday and weekend activity using other measures of physical activity in children have been equivocal. Trost *et al*.[218] found that children accumulated more accelerometer counts on weekends when compared to weekdays. In contrast, Gavarry *et al*.[81] used heart rate monitoring to show a significant decrease in children's activity during free days. The latter authors proposed that social and cultural factors may be responsible for the discrepancies among studies. An understanding of the types of activity occurring at school and at home may help to explain such differences. To our knowledge, only one other study used pedometers to investigate weekend activity in children.[179] Although the mean weekday step count (9,504) was slightly greater than the mean weekend step count (9,005), data were collected by the participants using various self-report techniques that have yet to be validated. Consequently, it is difficult to establish if the difference in weekday and weekend steps demonstrated in the present study is distinctive to New Zealand children.

Significant differences in activity were also observed between sexes, with boys 14.2% and 13.8% more active than girls on weekdays and weekends, respectively. This was not surprising given that sex is the most frequent correlate of physical activity identified in previous research.[185] Our step count data also showed a negative association with age on weekends but not on weekdays. Although there is convincing evidence of an age-related decline in physical activity during adolescence, data representing preadolescent children are less consistent.[185] Trost *et al*.[219] reported a significant decrease in accelerometer counts during both childhood and adolescence. Conversely, Vincent *et al*.[237] found little effect of age on weekday step counts in their international cohort of 6-12-year-old children. This was supported by recent findings suggesting that a significant decline in weekday steps occurs during the transition from elementary school to high school.[129] Combining the latter findings with those from the present study, it seems likely that the number of steps accumulated by pre-adolescent children on weekdays is relatively constant. The divergence from previous accelerometry data may be a result of differences in methodology. For example, an age-related decline in non-ambulatory activity, such as cycling or swimming, would be detected by accelerometry but not by pedometry. In any case, our results suggest that age-related trends in physical activity behaviour may be accentuated in out-of-school environments. Similarly, grouping the sample by socioeconomic status revealed significant differences in weekend steps only. This is of interest given that the majority of previous research has found little evidence of an interaction between physical activity and socioeconomic indicators in children.[185] A possible explanation is that New Zealand schools are required to maintain a reasonable level of physical activity regardless of socioeconomic rating, whereas children from more privileged backgrounds may be given greater opportunity to be active during weekends. Thus, interventions that focus on promoting out-of-school activity in families from lower socioeconomic regions may be beneficial.

Although the mean weekday step counts in the present study appear higher than current international estimates,[237] the prevalence of overweight and obesity in the Australian and Swedish children (15.1% and 16.7%, respectively) was considerably lower than in our sample (26.5%). This apparent paradox may be explained by the relatively weak correlations between BMI and steps.day^{-1}. Our results showed similar trends to those reported by Vincent *et al*.[237], with no significant differences in weekday step counts among the three BMI categories. This may be due in part to the limitations of BMI as a tool for measuring childhood obesity. Previous research has raised the possibility of inter-individual variance in %BF at a given BMI among children from different ethnic backgrounds.[58] Consequently, the use of a universal BMI scale for classifying overweight and obesity may not be appropriate for children who differ from the typical European phenotype. Polynesian children, for instance, tend to have more fat-free mass and less fat mass at a given BMI when compared to European children.[182] In contrast, Asian children often show less fat-free mass and more fat mass than their European counterparts.[58] Although the degree of potential misclassification for each ethnic group is uncertain, it is likely that the trivial associations between mean step count and BMI status observed in this study reflect the shortcomings of BMI as a predictor of childhood obesity.

A key objective of this study was to determine if the implementation of body composition measures other than BMI would enable the detection of an association between steps.day^{-1} and childhood obesity. It is well established that central adiposity increases the risk of several negative health outcomes in childhood.[51] By grouping the sample according to the WC cut-offs proposed by Taylor *et al.*[208], we were able to compare step counts in children with normal and central patterns of fat distribution. Results showed that children with central adiposity averaged significantly fewer steps on weekdays and weekends than those with normal fat distribution. This is consistent with recent research suggesting that WC has stronger associations with physical activity in young people than BMI.[118] However, as with BMI, it remains possible that ethnic variation in body size may contribute to the potential misclassification of Polynesian and Asian children. The development of ethnic-specific cut-offs may address this issue.

Percentage body fat provides a more appropriate gauge of obesity than either BMI or WC. Criterion measures of body fat, such as dual-energy X-ray absorptiometry (DEXA), deuterium dilution, and underwater weighing, are costly and impractical for large-scale research. However, these reference standards can be used to calculate accurate ($r^2 > 0.95$) BIA prediction equations for describing %BF in children. BIA is an ideal technique for paediatric populations due to its portability and short operating time (5-10 min). It is also less invasive and has greater inter-rater reliability than skinfold testing, a common measure of body fat used in field studies. The main limitation of BIA is that the study sample must be comparable to the reference population from which the prediction equation was derived. Using a BIA equation cross-validated with deuterium dilution in New Zealand children, we found significant associations between the numbers of steps children accumulated each day and their level of body fatness. Boys and girls with excessive body fat averaged 1,554 and 1,893 (respectively) fewer steps each weekday than children with normal body fat levels. Although the differences were less pronounced on the weekends (1,480 and 844 for boys and girls, respectively), the significant association between %BF status and activity was similar across sexes and ethnic groups. This provides new evidence supporting the implementation of population-wide initiatives for increasing daily steps in children. Nevertheless, the cross-sectional design of this study precludes statements of cause and effect. A logical next step is to obtain longitudinal data monitoring trends in steps.day^{-1} and body fatness during development. This would enable conclusions to be made regarding the causal nature of the relation between steps and body fat in children. The effect of puberty on the association between daily step counts and body fatness also requires investigation. The sharp decline in steps.day^{-1} during the transition from childhood to adolescence reported previously[129] coincides with distinct changes in body composition. For example, at an equivalent BMI, adolescents who are sexually mature tend to have a lower %BF than those who are less developed.[50] Resolving the relationships between pedometer-determined activity and population measures of body composition at various stages of maturation is an important topic for future research.

Given the findings from the present study, we suggest that daily step count targets based on %BF are more relevant than either BMI- or WC-referenced standards. Currently, the only step count recommendations available for young people are based on BMI. Tudor-Locke *et al*.[224] proposed a target of 15,000 (boys) and 12,000 (girls) steps each weekday to minimise the risk of overweight or obesity as defined by international BMI cut-off points.[44] Before these step count standards can be verified using %BF, the levels of body fat that constitute an unhealthy child need to be determined. The development of sex- and age-specific %BF charts identifying increased health risk in young people would ensure that %BF-referenced step count targets are applicable to the population. Prospective recommendations should also allow for the significantly lower step counts on weekends when compared to weekdays. Yet another layer of complexity is added when one considers the potential differences in activity and body composition across ethnic groups within a population. Our results indicated that Asian children were the least active of the three ethnic groups in this study, whereas Polynesian children were the most active on weekdays. Interestingly, both Asian and Polynesian groups suffered from relatively high levels of body fat compared to Europeans. The high weekend step counts observed in European children may be related to the larger proportion of this ethnic group with a high socioeconomic rating (51.0%) when compared to Asian (42.3%) and Polynesian (8.4%) children. Such ethnic variation, although an important consideration when tailoring obesity prevention initiatives, may not be practical to include in population step count recommendations.

In summary, this study provides the first step count data for young New Zealanders, revealing differences in physical activity across sex, age, and socioeconomic groups, and among European, Polynesian and Asian children. The utilization of MDM pedometers enabled us to detect significantly lower levels of activity during weekends when compared to weekdays. Furthermore, the results of this study offer new evidence of a link between daily steps and body fatness in children. Given that daily steps were more strongly related with body fat than either BMI or WC, we recommend the use of %BF as an indicator of childhood obesity in physical activity research. These findings advance the current state of knowledge regarding physical activity and body composition in children, and provide support for the development of strategies to increase the accumulation of daily steps in paediatric populations.

CHAPTER 6

DAILY STEP COUNT RECOMMENDATIONS FOR CHILDREN

Preface

The preceding chapter demonstrated that %BF is more closely related to pedometer steps in children than BMI. However, current criterion-referenced step count recommendations for children were determined from BMI measurements. It follows that step count targets based on body fatness would be more appropriate than existing guidelines. The purpose of this chapter was to estimate the optimal daily step count targets for children using %BF as the criterion reference. The findings presented here represent the first physical activity recommendations developed from New Zealand data, and are used in the following chapter to distinguish between active and inactive children. The paper resulting from this chapter was published as a Short Communication in the January 2007 issue of *Preventive Medicine* (Appendix A).

Abstract

Objective: Current recommendations for pedometer-determined physical activity in children (boys, 15,000 steps.day^{-1}; girls, 12,000 steps.day^{-1}) were based on the association between weekday step counts and body mass index. The objective of this study was to develop new targets using both weekday and weekend step counts with percentage body fat (%BF) as the criterion reference.

Methods: The %BF of 969 New Zealand European, Polynesian, and Asian children (515 male, 454 female) aged 5-12 years was measured using hand-to-foot bioelectrical impedance analysis. Weekday and weekend step counts, assessed using sealed multiday memory pedometers over five days, were combined into a scaled mean step count. The contrasting groups method for determining criterion-referenced cut-off points was used to establish the optimal step count values for predicting overweight (%BF > 85th percentile) and non-overweight (%BF < 85th percentile).

Results: Overweight children had significantly lower mean step counts (14,238 ± 3,343, boys; 12,555 ± 3,169, girls) than non-overweight children (16,106 ± 3,208, boys;

14,176 ± 2,728, girls). Optimal step count cut-off points were 16,000 steps.day^{-1} for boys and 13,000 steps.day^{-1} for girls.

Conclusion: Step count targets for reducing the risk of excess body fat in children are 1,000 steps.day^{-1} higher than existing BMI-referenced guidelines.

Introduction

Regular physical activity provides numerous health benefits for people of all ages.[231] As such, the promotion of habitual activity has become a key public health priority in many countries. Step-counting pedometers are an effective motivational tool in this regard, offering an inexpensive and straightforward means to monitor the accumulation of daily activity.[198] In order to guide pedometer-based surveillance and interventions, daily step count targets related to positive health outcomes are essential. In adults, 10,000 steps.day^{-1} has gained acceptance as an appropriate public health message for reducing the risk of overweight.[222] However, children average significantly greater levels of activity than adults regardless of their body size,[62] suggesting that higher step count targets are required.

Tudor-Locke *et al*.[224] recently used body mass index (BMI) as a criterion for developing pedometer-determined activity recommendations in children. Daily step count targets of 15,000 (boys) and 12,000 (girls) were proposed as the optimal cut-off points for predicting normal and overweight BMI. Subsequent evidence suggests that step counts are more strongly associated with percentage body fat (%BF) than with BMI in children.[62] This is not surprising given that BMI does not distinguish between lean and fat mass, and provides a less direct estimate of adiposity than %BF.[254] Furthermore, existing guidelines were developed from weekday steps only. Previous pedometry studies in children have observed significantly fewer steps on weekend days than on weekdays.[62,179] Given that step count targets are applicable on weekdays and weekends, it is important to consider differences in activity between these days during the development process. The purpose of this study was to replicate the analyses undertaken by Tudor-Locke *et al*.[224] using both weekday and weekend step count data with %BF as the criterion reference. This will provide new step count targets more closely related to health outcomes than current recommendations.

Methods

Participants

Participant recruitment and data collection procedures are described in detail elsewhere.[62] Briefly, 969 children (454 boys, 515 girls) aged 5-12 years were randomly selected from 27 elementary schools in Auckland, New Zealand. The ethnic composition of the sample was 49.6% European (228 boys, 253 girls), 28.7% Polynesian (128 boys, 150 girls), 17.3% Asian (81 boys, 87 girls), and 4.3% from other ethnicities (17 boys, 25 girls). Ethical approval was obtained from our institutional ethics committee (Appendix D). Each participant and their legal guardian provided written informed consent.

Measures

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 squared height (m^2). Resistance measurements were obtained using a hand-to-foot bioelectrical impedance analyser (Model BIM4, Impedimed, Capalaba, Australia) with a tetrapolar arrangement of self-adhesive electrodes (Red Dot 2330, 3M Healthcare, St Paul, MN, USA). A prediction equation previously validated with deuterium dilution in New Zealand children aged 5-14 years ($r^2 = 0.96$, SEE = 2.44 kg) was used to derive fat-free mass (FFM) from resistance, height, and weight.[182] %BF was then calculated as the difference between weight and FFM divided by weight and multiplied by 100. Overweight (including obese) children were classified according to international BMI cut-off points[44] and the 85th percentile of %BF for each age and sex group. The latter criterion was chosen as it provides the closest approximation to the overweight boundaries of international BMI curves.[146]

Habitual physical activity was measured using sealed multiday memory pedometers (Model NL-2000, New Lifestyles Inc., Lee's Summit, MO) over three weekdays and two weekend days. An overall mean step count was obtained after scaling the averaged data by a ratio of five weekdays to two weekend days. Data were excluded if participants did not wear the pedometer for more than one hour on a given day (as determined by a parent proxy questionnaire; Appendix I). Daily step counts below 1,000 or above 30,000 were regarded as outliers and were removed.[179]

Statistical Analyses

The difference in mean step counts between overweight and non-overweight children was examined separately for BMI and %BF using two-tailed independent samples *t*-tests. Each analysis sample was divided into overweight children and a random selection of age- and sex-matched non-overweight children. The contrasting groups method for determining criterion-referenced cut points, described previously by Tudor-Locke *et al*.[224], utilises several statistical approaches to establish the predictive ability of a given cutting score: (1) probability of correct decisions; (2) misclassification errors; (3) validity coefficient; and (4) utility analysis. The *probability of correct decisions* represents the probability of correct classifications of 'true non-overweight' and 'true overweight' against the probability of incorrect classifications of 'false non-overweight' and 'false overweight'; the highest score is considered optimal. *Misclassification errors* are Type I (false overweight) and Type II error (false non-overweight) probabilities that estimate the likelihood of incorrect classification. In this case, the cut-off point that minimises the error is optimal. The *validity coefficient* measures the extent to which a particular cut-off point accurately predicts weight status. The cut-off point with the highest validity coefficient will produce the highest probability of correct decisions. *Utility analysis* provides an estimate of the expected maximum utility for a given cut-off point. The largest expected maximum utility value indicates the optimal cut-off point. The value of each index was calculated for a range of potential step count targets in order to determine the optimal cut-off point. Data were analysed using SPSS version 12.0.1 for Windows (SPSS Inc., Chicago, IL).

Results

Table 6-1 shows the mean scaled step counts for boys and girls grouped by BMI and %BF status. The prevalence of overweight was 22.7% (BMI) and 14.0% (%BF) for boys, and 30.2% and 16.3% for girls. Children classified as overweight using %BF had significantly lower step counts than their non-overweight counterparts. No significant differences in step counts were observed between BMI categories.

Table 6-1. Pedometer-determined physical activity for main study sample stratified by BMI and %BF status.

Measure	Sex	Non-Overweight Steps.Day^{-1}	Overweight Steps.Day^{-1}
BMI	Male	15,205 ± 3,490 (117)	14,750 ± 3,704 (117)
	Female	13,294 ± 3,420 (137)	13,198 ± 3,420 (137)
%BF	Male	16,106 ± 3,208 (72)	14,238 ± 3,343 (72)[a]
	Female	14,176 ± 2,728 (74)	12,555 ± 3,169 (74)[a]

Data are presented as mean ± SD, with sample size in parentheses.
[a]Significantly different Non-Overweight ($P < 0.005$).

A summary of the contrasting groups method for determining %BF-referenced step count targets is presented in Table 6-2. The optimal step count cut-off points for predicting %BF status were 16,000 steps.day^{-1} for boys and 13,000 steps.day^{-1} for girls.

Discussion

This study provides the first opportunity to assess the appropriateness of the BMI-referenced step count guidelines for children proposed by Tudor-Locke *et al.*[224] The collection of both weekday and weekend steps with %BF as the criterion reference enabled us to investigate the predictive ability of a series of prospective cut-off points. Our results indicate that existing guidelines (15,000 step/day for boys, 12,000 steps.day^{-1} for girls) are reasonable targets for children. However, cut points of 16,000 and 13,000 steps.day^{-1} were the best predictors of body fat status in this sample, and therefore an increase of 1,000 steps.day^{-1} for boys and girls aged 5-12 years should be considered. Previous research suggests that 1,000 steps is a worthwhile increase in daily activity with respect to improving health outcomes.[224]

The variation in results between studies may be explained by the different techniques used to measure and define overweight. There is substantial evidence that BMI is a mediocre indicator of overweight in children from non-European ethnic groups.[58,182] Indeed, there were no significant relationships between BMI status and steps.day^{-1} in our multiethnic sample. In addition, daily recommendations that do not account for a reduction in steps on weekend days[62,179] may overestimate the level of activity required for health benefits. To avoid this potential source of error, we transformed weekday and weekend data into a scaled average that reflected the overall contribution of each day type to weekly activity. An alternative would be to issue discrete guidelines for weekdays and weekend days, however this option may be unnecessarily complicated for health promotion purposes.

It should also be noted that Tudor-Locke *et al*.[224] collected data from predominantly European communities in Australia, Sweden, and the USA. Thus, the divergence from our results may also be attributable to differences in population characteristics. The positive associations between steps.day^{-1} and BMI in their international cohort were not observed in our sample, suggesting that at least some differences do exist. Population-specific step count guidelines may be warranted if the relationship between body fatness and physical activity also varies between countries or ethnicities. It is clear that this issue requires further investigation.

In summary, our results confirm that daily step count guidelines for children should be set considerably higher than those for adults. Based on %BF status, we propose targets of 16,000 and 13,000 steps.day^{-1} for boys and girls (respectively). This corresponds to a 1,000 steps.day^{-1} increase over existing BMI-referenced guidelines.

Table 6-2. Determination of optimal step count cut-off points for boys and in the main study sample using the contrasting groups method.

Steps.Day^{-1}	Probability of Correct Decisions	Misclassification Errors (Type I/Type II)	Validity Coefficient	Utility Analysis		
				Expected Utility	Expected Disutility	Expected Maximum Utility
Male						
10,000	0.53	0.01/0.45	0.14	0.53	-0.47	10
11,000	0.57	0.02/0.41	0.22	0.57	-0.43	20
12,000	0.58	0.05/0.38	0.20	0.58	-0.42	22
13,000	0.58	0.08/0.33	0.19	0.58	-0.42	24
14,000	0.61	0.13/0.26	0.23	0.61	-0.39	32
15,000	0.60	0.20/0.20	0.19	0.60	-0.40	28
16,000[a]	**0.62**	**0.26/0.13**	**0.24**	**0.62**	**-0.38**	**34**
17,000	0.60	0.30/0.10	0.23	0.60	-0.40	30
18,000	0.57	0.37/0.06	0.18	0.57	-0.43	20
Female						
10,000	0.59	0.03/0.37	0.26	0.59	-0.41	28
11,000	0.59	0.06/0.35	0.22	0.59	-0.41	26
12,000	0.60	0.13/0.27	0.21	0.60	-0.40	30
13,000[a]	**0.65**	**0.16/0.20**	**0.30**	**0.65**	**-0.35**	**44**
14,000	0.61	0.22/0.17	0.22	0.61	-0.39	32
15,000	0.62	0.28/0.10	0.26	0.62	-0.38	36
16,000	0.55	0.37/0.07	0.13	0.55	-0.45	16
17,000	0.52	0.43/0.05	0.06	0.52	-0.48	6
18,000	0.51	0.46/0.03	0.03	0.51	-0.49	2

[a]Optimal step count cut-off point.

CHAPTER 7

CORRELATES OF OBESITY IN NEW ZEALAND CHILDREN

Preface

This chapter represents the second major section of this thesis (the first being Chapter 5), and examines the key correlates of obesity in a large sample of New Zealand children. While previous chapters have demonstrated a relationship between physical activity and excess body fatness, several demographic and lifestyle-related risk factors were also collected from participants. An understanding of the characteristics associated with obesity in children is essential for the development of interventions and for targeting high risk groups. This chapter examines the odds of overfat in children with a range of selected risk factors, thereby providing valuable information describing the correlates of obesity in this population. The paper resulting from this chapter was accepted for publication in *Asia Pacific Journal of Clinical Nutrition* (August, 2007) and is currently in press.

Abstract

Objective: To identify demographic and lifestyle risk factors for excess body fatness in a multiethnic sample of New Zealand children.

Methods: A total of 1229 New Zealand children aged 5-12 years (603 male, 626 female) participated in the study. The ethnic composition of the sample was 46.8% European, 33.1% Polynesian, 15.9% Asian, and 4.1% from other ethnicities. Percentage body fat (%BF) was measured using hand-to-foot bioelectrical impedance analysis, and overfat participants were defined as those with a %BF greater than 25% (boys) and 30% (girls). A parent proxy questionnaire was developed for assessing demographic and lifestyle factors, and multiday memory pedometers were used to estimate physical activity levels over five days.

Results: After controlling for differences in sex, age, and socioeconomic status (SES), Asian children were more likely to have excess body fat than European children. The adjusted odds of overfat also increased with age and decreased with SES. Three lifestyle risk factors related to fat status were identified: low physical activity, skipping

breakfast, and insufficient sleep on weekdays. Clustering of these risk factors resulted in a cumulative increase in the prevalence of overfat. Active transport, sports participation, lunch bought at school, fast food consumption, sugary drink consumption, and weekend sleep duration were not associated with fat status after adjustment for the selected demographic variables.

Conclusion: The findings from this study enhance our understanding of the risk factors for excess body fatness in New Zealand children, and highlight key demographic and lifestyle priorities for future interventions.

Introduction

The prevalence of overweight and obesity in children has reached epidemic proportions in many countries. Given the long-term economic and public health consequences associated with childhood obesity, the development of preventative strategies for reducing the accretion of excess fat in young people is essential. However, obesity is a complex disorder that is modulated by interactions between environmental and behavioural factors, and consequently isolating the key predictors of obesity in young people can be challenging.

Potential risk factors for obesity are commonly categorised as either demographic (non-modifiable) or lifestyle (modifiable) factors. An understanding of the demographic risk factors related to obesity can help prioritise the population groups to be targeted by public health initiatives. For example, there is evidence that the prevalence of childhood obesity in developed countries is relatively high among certain ethnic minorities[94,188,199] and in those from underprivileged backgrounds.[37,52,242] Nonetheless, the interplay between socioeconomic status (SES) and ethnicity and their effects on obesity remain unclear. It has been hypothesised that the high occurrence of obesity in some ethnic minorities is due to their overrepresentation in low socioeconomic regions.[241] Subsequent research suggests that SES is not the only contributor to ethnic differences in childhood obesity, but that other ethnic-specific variables (e.g., body composition, culture, maturation) may have important roles.[86,87,245]

While demographic risk factors are useful for isolating the population groups most susceptible to obesity, lifestyle factors reflect the underlying behaviours that promote excessive fat accumulation. A wide range of potential lifestyle risk factors for childhood obesity have been investigated with variable results.[165] The most consistent predictors of obesity in children are low levels of physical activity,[66,109,154,217] unhealthy dietary patterns,[14,82,85,210,235] and insufficient sleep.[1,37,193,240] However, there is limited information describing the interactions among multiple risk factors and their cumulative (or confounding) effects on children's adiposity. The only study to address this issue investigated overweight and obesity in German children aged 5-7 years with various combinations of three demographic risk factors (parental overweight, low SES, and high birth weight).[52] On average, children that had two risk factors were more likely to be overweight or obese than those with single risk factors, with the highest prevalence values observed when all three risk factors were combined. The potential effects of clustering modifiable risk factors have yet to be assessed.

Further complications arise when the different methods used to classify obesity in children are considered. Most previous studies have used age- and sex-specific body mass index (BMI) percentiles to define obesity. This is despite evidence that BMI may not provide an equivalent estimate of body fatness across different ethnic groups due to its inability to distinguish between fat and fat-free mass.[58,182] Furthermore, the relationship between the BMI percentiles used to define childhood obesity and negative health outcomes is uncertain. As such, risk factors for BMI-determined obesity may not necessarily correspond to a higher risk of morbidity. Several studies have proposed sex-specific percentage body fat (%BF) limits ranging from 20% to 30% that coincide with elevated risk of health complications in children.[65,243,249] These health-related %BF criteria may provide more relevant reference points for determining obesity risk factors than existing BMI standards.

It is clear that an awareness of the factors associated with excessive fat accrual in children is essential to counteract the current obesity trends. Despite evidence that the average BMI of young New Zealanders is rapidly increasing,[227] there is no information describing the predictors of body fatness in this population. Thus, the primary objective of this study was to identify key demographic and lifestyle factors associated with increased risk of excess adiposity in a multiethnic sample of New Zealand children. A secondary objective was to examine the effects of risk factor clustering on the prevalence of overfat in children.

Methods

Participants

A total of 1 229 children (603 boys, 626 girls) aged 5-12 years were randomly selected from 27 primary (elementary) schools in Auckland, New Zealand. Participating schools were purposively sampled to replicate the geographic and socioeconomic distribution of primary schools in the Auckland district. The ethnic composition of the sample was 46.8% European (283 boys, 292 girls), 33.1% Polynesian (201 boys, 206 girls), 15.9% Asian (99 boys, 97 girls), and 4.1% from other ethnicities (20 boys, 31 girls). The Polynesian ethnic group was composed of Pacific Island (58.2%) and Maori (41.8%) children, and the Asian group was composed of Indian (38.3%), Chinese (21.9%), Korean (13.8%), Filipino (9.7%), Sri Lankan (4.1%), and Other Asian (12.2%) children. SES was estimated using the Ministry of Education decile classification system for New Zealand primary schools. For the purposes of this study, participants from schools with a decile rating between 1 and 3 were categorised into the 'Low' SES group, and those from schools rated between 4 to 7 and between 8 to 10 were considered 'Middle' and 'High', respectively. Ethical approval for this study was obtained from the Auckland University of Technology Ethics Committee (Appendix D). Written informed consent was provided by each participant and his or her legal guardian.

Measurements and Procedures

The height of each participant was measured to the nearest millimetre with a portable stadiometer (Design No. 1013522, Surgical and Medical Products, Seven Hills, Australia), and weight was assessed to the nearest 0.1 kg on a digital scale (Model Seca 770, Seca, Hamburg, Germany). Body mass index (BMI) was calculated as weight (kg) divided by squared height (m^2). Resistance (R) measurements were obtained at 50 kHz using a bioelectrical impedance analyser (Model BIM4, Impedimed, Capalaba, Australia) with a tetrapolar arrangement of self-adhesive electrodes (Red Dot 2330, 3M Healthcare, St Paul, MN, USA). After swabbing the skin on the right hand and foot with alcohol, source electrodes were placed on the dorsal surface of the foot over the distal portion of the second metatarsal, and on the hand on the distal portion of the second metacarpal. Sensing electrodes were placed at the anterior ankle between the tibial and the fibular malleoli, and at the posterior wrist between the styloid processes of the radius and ulna. Testing was initiated after the participants emptied their bladder, and had been lying supine with their arms and legs abducted for at least 10 min. Testing was completed when repeated measurements of R were within 1 Ω of each other. Fat and fat-free mass were calculated from R, height, and weight using a prediction equation previously validated in New Zealand children.[182] %BF was derived as fat mass divided by weight and multiplied by 100. Boys and girls were classified as 'overfat' if their %BF exceeded 25% and 30% (respectively).[249]

Sealed multiday memory pedometers (Model NL-2000, New Lifestyles Inc, Lee's Summit, MO) were used to measure daily steps over three weekdays and two weekend days. An overall mean step count was obtained after scaling the averaged data by a ratio of five weekdays to two weekend days. Recent step count guidelines of 16 000 (boys) and 13 000 (girls) steps.day^{-1} were used to categorise participants into 'active' and 'inactive' groups.[63] Data were excluded if participants did not wear their pedometer for more than one hour on a given day (as determined by a parent proxy questionnaire; Appendix I). Daily step counts below 1 000 or above 30 000 were regarded as outliers and were removed.[179]

A proxy questionnaire was administered to the parents of each participant to collect information about potential risk factors for obesity while avoiding the recall error associated with self-report surveys in children (Appendix J).[184] Parents were asked how their child usually travelled to and from school, with responses grouped into active (walking, cycling) or motorised transport (car, bus, train). Frequency of breakfast, fast food, and sugary drink consumption in the last full week was determined (servings per week), as were the number of weekdays the participants purchased lunch at school (zero to five days). Participation in organised sport outside of school was assessed for the last full week (zero to seven days). Parents were also asked what time their child usually goes to bed and gets up from bed on weekdays and weekends. The difference between the two times provided the total minutes of sleep for each participant.

Statistical Analyses

Data were analysed using SPSS version 14.0 for Windows (SPSS Inc., Chicago, IL). Differences in participant characteristics (age, height, weight, BMI, and %BF) between sexes and among ethnic groups were assessed by two-way ANOVA, with significant associations examined by pairwise comparisons using *t*-tests. Logistic regression analysis was used to investigate associations between excess body fatness and selected demographic and lifestyle variables. Odds ratios for each category were adjusted for sex, age, ethnicity, and SES. Ethnic differences in the frequencies of sex, age, and SES categories were examined using chi-squared testing. Analysis of covariance was used to compare the mean %BF between children with and without selected risk factor clusters while adjusting for age, ethnicity, and SES. Differences in the prevalence of overfat were examined using chi-squared analysis. A *P* value less than 0.05 was used to indicate statistical significance.

Results

The physical characteristics of the three major ethnicities in this study are presented in Table 7-1. No significant differences in age or height were observed between sexes or among ethnic groups. Polynesian boys and girls were heavier and had higher BMI values than their European and Asian counterparts. European children had less body fat than Polynesian and Asian children of the same sex, although the difference between European and Asian girls was not statistically significant. Boys averaged less body fat than girls across the whole sample and within each ethnic group.

Table 7-1. Participant characteristics for the main study sample.

	European		Polynesian		Asian		All	
	M (*N* = 283)	F (*N* = 292)	M (*N* = 201)	F (*N* = 206)	M (*N* = 99)	F (*N* = 97)	M (*N* = 603)	F (*N* = 626)
Age (yr)	8.2 ± 1.8	8.4 ± 1.7	8.4 ± 1.8	8.4 ± 1.8	8.6 ± 1.7	8.6 ± 1.8	8.4 ± 1.8	8.4 ± 1.8
H (cm)	131.0 ± 12.1	131.0 ± 11.7	132.9 ± 12.8	132.9 ± 13.0	130.6 ± 10.3	130.1 ± 12.5	131.6 ± 12.0	131.4 ± 12.2
W (kg)	29.9 ± 8.6[a]	30.4 ± 9.7[a]	35.3 ± 13.0	35.7 ± 13.9	30.0 ± 8.3[a]	29.3 ± 9.2[a]	31.7 ± 10.5	31.9 ± 11.4
BMI ($kg{\cdot}m^{-2}$)	17.1 ± 2.4[a]	17.3 ± 2.8[a]	19.4 ± 4.3	19.5 ± 4.4	17.3 ± 2.8[a]	16.9 ± 2.8[a]	17.9 ± 3.4	18.0 ± 3.6
%BF	17.4 ± 6.0[b]	21.2 ± 6.4[c]	20.4 ± 7.5[bd]	23.1 ± 7.3	20.1 ± 6.8[bd]	23.2 ± 7.5	18.9 ± 6.9[b]	22.2 ± 6.9

Data are presented as mean ± SD. M, male; F, female; BMI, body mass index.
[a]Significantly different from Polynesian of same sex ($P < 0.01$).
[b]Significantly different from female of same ethnic group ($P < 0.01$).
[c]Significantly different from Polynesian of same sex ($P < 0.05$).
[d]Significantly different from European of same sex ($P < 0.01$).

Table 7-2 shows the unadjusted and adjusted odds ratios for excess body fatness for each of the demographic and lifestyle variables assessed. Initial analyses indicated significant associations between fat status and age, ethnicity, SES, physical activity, breakfast, bought lunch, fast food, sugary drinks, and weekday sleep. Adjusting for differences in sex, age, ethnicity, and SES negated associations between fat status and bought lunch, fast food, and sugary drink consumption. The adjusted odds ratios for three of the four demographic variables remained significant. The odds of overfat were 15.4 times greater in 11-12-year-old children than those aged 5-6 years. In addition, the odds of overfat in children from the low SES group were 1.6 and 2.7 times greater than children in the middle and high groups, respectively. While the odds of overfat in Asian children were 1.8 times greater than in European children, differences were not significant for the other two ethnic groups.

Adjusting for demographic differences had a noticeable effect on the odds of overfat between ethnic groups, but not between sex, age, or SES categories. Further analyses revealed no significant variation in sex ($P = 0.539$) or age ($P = 0.561$) distributions among the ethnic groups. In contrast, the SES distribution differed significantly by ethnicity ($P < 0.001$): 73.2% of Polynesian children were in the low SES group and only 8.4% were in the high SES group, compared with 15.8% and 51.0% for European children, and 25.5% and 42.3% for Asian children. To investigate the interaction between SES and ethnicity on fat status, the effects of SES on the odds of overfat were determined for the three major ethnic groups in this study (Figure 7-1). European and Asian children with a low SES had odds of overfat that were 2.6 and 3.3 times greater (respectively) than their high SES counterparts (European, $P = 0.006$; Asian, $P = 0.004$). Although Polynesian children in the Low and Middle SES groups had odds of overfat that were 2.9 and 3.8 times greater (respectively) than those in the High SES group, the difference was significant for the Middle SES group only ($P = 0.044$). There were no significant differences in the odds of overfat between Middle and High SES groups for European ($P = 0.395$) and Asian ($P = 0.430$) ethnicities.

Physical activity, breakfast consumption, and weekday sleep hours were the only lifestyle factors significantly associated with fat status after adjustment for the selected demographic variables (Table 7-2). Children who accumulated less than 16 000 (boys) and 13 000 (girls) steps.day^{-1} had odds of overfat that were 2.2 times greater than children who reached these targets. Similarly, the odds of overfat for children who had breakfast on 1-2 or 3-4 days in the preceding week were 1.9 and 1.8 times greater (respectively) than those who had breakfast on five or more days. Of all the lifestyle risk factors, children that sleep for less than 12 hours on weekdays had the highest odds of overfat, rising from 3.4 in the 11-11.9 hour group to 5.3 in the < 10 hour group. Active transport, sports participation, and weekend sleep patterns were not associated with fat status either before or after adjustment for sex, age, ethnicity, and SES.

The associations between body fatness, overfat prevalence, and various combinations of the lifestyle risk factors identified in this study (inactivity, skipping breakfast, and low weekday sleep) were assessed separately for boys and girls while adjusting for differences in age, ethnicity, and SES (Table 7-3). Overall, larger differences in %BF were detected with clusters of two and three risk factors when compared with the single risk factor categories. Although children with lifestyle risk factors showed a greater prevalence of overfat than those without the risk factor(s), not all of the differences between cluster levels were statistically significant. For both boys and girls, chi-squared analysis revealed that the overfat prevalence in the inactive + low breakfast group was significantly higher than in the inactive group (boys, $P = 0.003$; girls, $P = 0.046$), but not in the low breakfast group (boys, $P = 0.286$; girls, $P = 0.266$). Similarly, combining the low breakfast and low weekday sleep groups resulted in a significant increase in overfat when compared with the low weekday sleep group (boys, $P = 0.001$; girls, $P = 0.017$), but not with the low breakfast group (boys, $P = 0.240$; girls, $P = 0.238$). No significant differences were detected between the inactive + low weekday sleep group and each individual risk factor. These findings suggest that skipping breakfast has the greatest effect on the prevalence of excess fatness in this sample. Indeed, the increase in overfat when combining all three risk factors was only significant (boys, $P = 0.004$; girls, $P = 0.042$) when compared to the two-factor cluster that did not already include the low breakfast group (inactive + low weekday sleep).

Table 7-2. Correlates of overfat (%BF ≥ 25% [boys] and 30% [girls]) in the main study sample.

	Number of Participants (%)		Unadjusted Odds Ratio (95% CI)	Adjusted Odds Ratio (95% CI)[a]
	Non-overfat	Overfat		
Sex				
Male	500 (48.4%)	103 (52.6%)	1.00	1.00
Female	533 (51.6%)	93 (47.4%)	0.85 (0.62-1.15)	0.82 (0.59-1.13)
Age				
5-6 years	217 (21.0%)	8 (4.1%)	1.00	1.00
7-8 years	375 (36.3%)	37 (18.9%)	2.68 (1.22-5.85)[b]	2.76 (1.25-6.06)[b]
9-10 years	317 (30.7%)	87 (44.4%)	7.44 (3.54-15.67)[c]	7.84 (3.70-16.61)[c]
11-12 years	124 (12.0%)	64 (32.7%)	14.00 (6.50-30.16)[c]	15.40 (7.07-33.52)[c]
Ethnicity				
European	514 (49.8%)	61 (31.1%)	1.00	1.00
Polynesian	318 (30.8%)	89 (45.4%)	2.36 (1.65-3.36)[c]	1.48 (0.96-2.28)
Asian	157 (15.2%)	39 (19.9%)	2.09 (1.35-3.25)[c]	1.78 (1.12-2.83)[b]
Other	44 (4.3%)	7 (3.6%)	1.34 (0.58-3.11)	0.97 (0.40-2.36)
SES				
High	384 (37.2%)	41 (20.9%)	1.00	1.00
Middle	295 (28.6%)	50 (25.5%)	1.59 (1.02-2.47)[b]	1.59 (1.00-2.54)[b]
Low	354 (34.3%)	105 (53.6%)	2.78 (1.88-4.10)[c]	2.73 (1.70-4.38)[c]
Physical Activity				
Active	431 (51.2%)	51 (30.7%)	1.00	1.00
Inactive	410 (48.8%)	115 (69.3%)	2.37 (1.66-3.39)[c]	2.26 (1.54-3.34)[c]
Active Transport				
None	555 (54.4%)	92 (47.4%)	1.00	1.00
To or From School	133 (13.0%)	26 (13.4%)	1.18 (0.73-1.90)	1.12 (0.67-1.86)
To and From School	333 (32.6%)	76 (39.2%)	1.38 (0.99-1.92)	0.98 (0.69-1.41)
Sports Participation				
None	312 (31.0%)	54 (28.0%)	1.00	1.00
1-2 days/wk	414 (41.1%)	89 (46.1%)	1.24 (0.86-1.80)	1.29 (0.87-1.92)
3-4 days/wk	209 (20.7%)	30 (15.5%)	0.83 (0.51-1.34)	0.72 (0.43-1.20)
5+ days/wk	73 (7.2%)	20 (10.4%)	1.58 (0.89-2.81)	1.14 (0.62-2.12)
Breakfast				
None	13 (1.3%)	5 (2.6%)	2.38 (0.84-6.76)	1.46 (0.47-4.55)
1-2 days/wk	43 (4.2%)	20 (10.3%)	2.87 (1.64-5.02)[c]	1.88 (1.02-3.47)[b]
3-4 days/wk	53 (5.2%)	22 (11.3%)	2.56 (1.51-4.34)[c]	1.82 (1.02-3.26)[b]
5+ days/wk	908 (89.3%)	147 (75.8%)	1.00	1.00
Bought Lunch				
None	603 (59.2%)	107 (55.2%)	1.00	1.00
1-2 days/wk	341 (33.5%)	65 (33.5%)	1.07 (0.77-1.50)	0.83 (0.58-1.20)
3-4 days/wk	33 (3.2%)	13 (6.7%)	2.22 (1.13-4.36)[b]	1.53 (0.73-3.20)
5+ days/wk	42 (4.1%)	9 (4.6%)	1.21 (0.57-2.55)	0.71 (0.32-1.56)
Fast Food				
None	267 (26.3%)	39 (20.1%)	1.00	1.00
1-2 servings/wk	693 (68.3%)	141 (72.7%)	1.39 (0.95-2.04)	1.42 (0.94-2.15)
3-4 servings/wk	47 (4.6%)	9 (4.6%)	1.31 (0.60-2.88)	0.94 (0.41-2.18)
5+ servings/wk	7 (0.7%)	5 (2.6%)	4.89 (1.48-16.17)[c]	3.46 (0.94-12.70)
Sugary Drink				
None	159 (15.6%)	22 (11.4%)	1.00	1.00
1-2 servings/wk	465 (45.5%)	72 (37.3%)	1.12 (0.67-1.86)	1.09 (0.63-1.88)
3-4 servings/wk	189 (18.5%)	46 (23.8%)	1.76 (1.02-3.05)[b]	1.61 (0.90-2.90)
5+ servings/wk	208 (20.4%)	53 (27.5%)	1.84 (1.08-3.16)[b]	1.56 (0.87-2.79)
Weekday Sleep				
≥ 12 hr	92 (9.2%)	4 (2.2%)	1.00	1.00
11-11.9 hr	482 (48.1%)	70 (37.6%)	3.34 (1.19-9.38)[b]	3.36 (1.16-9.76)[b]
10-10.9 hr	363 (36.2%)	89 (47.8%)	5.64 (2.02-15.76)[c]	3.96 (1.36-11.53)[b]
< 10 hr	66 (6.6%)	23 (12.4%)	8.02 (2.65-24.27)[c]	5.25 (1.62-16.94)[c]
Weekend Sleep				
≥ 12 hr	138 (14.0%)	20 (11.2%)	1.00	1.00
11-11.9 hr	362 (36.8%)	50 (28.1%)	0.95 (0.55-1.66)	1.01 (0.56-1.84)
10-10.9 hr	358 (36.4%)	78 (43.8%)	1.50 (0.89-2.55)	1.31 (0.74-2.33)
< 10 hr	125 (12.7%)	30 (16.9%)	1.66 (0.90-3.06)	1.05 (0.54-2.06)

[a]Adjusted for sex, age, ethnicity, and SES.
[b]Significantly different from reference group ($P < 0.05$).
[c]Significantly different from reference group ($P < 0.01$).

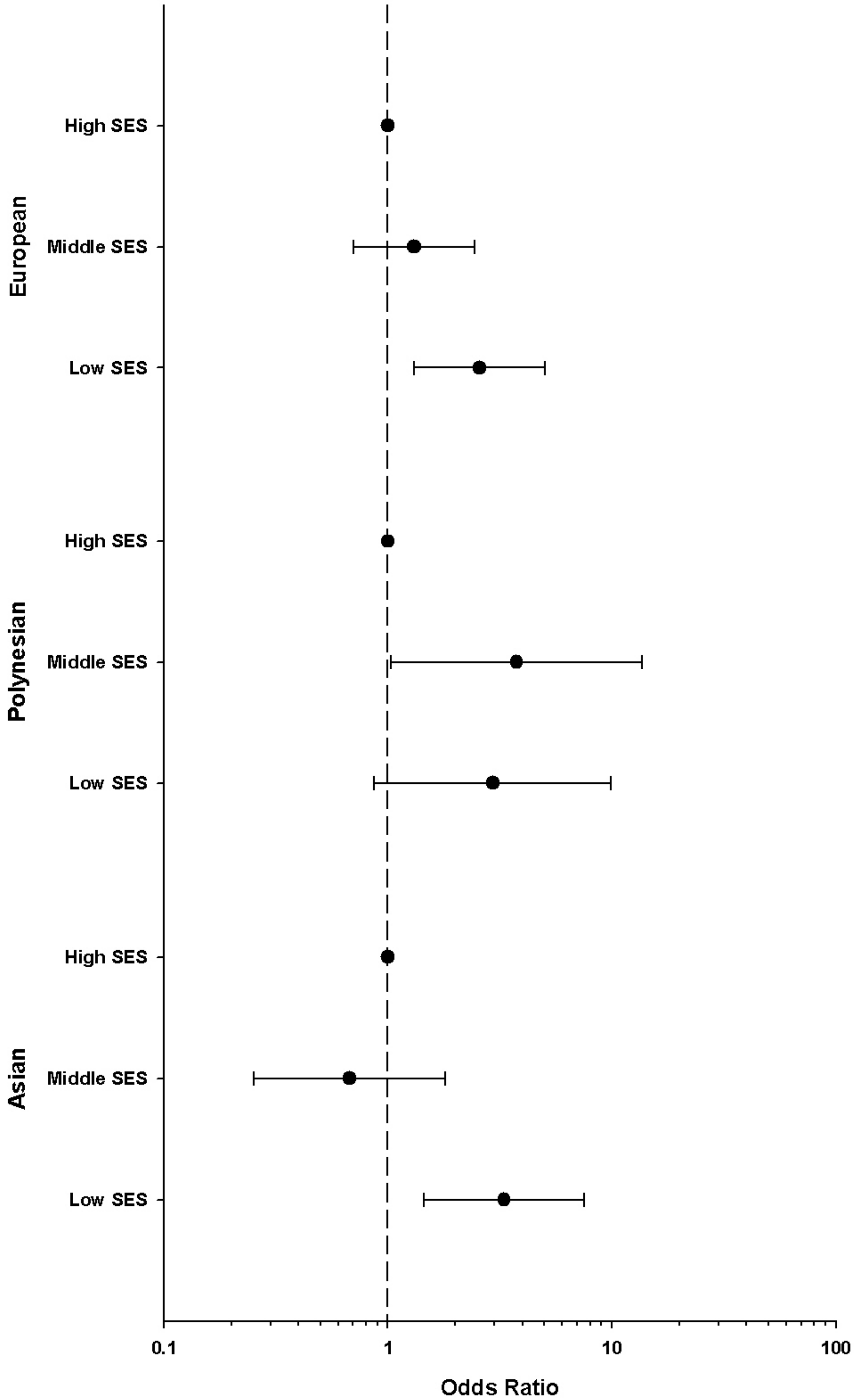

Figure 7-1. Odds ratios (± 95% CI) for overfat (%BF ≥ 25% [boys] or 30% [girls]) in European, Polynesian, and Asian children from Low, Middle, and High SES groups.

Table 7-3. Body fat and prevalence of overfat (%BF ≥ 25% [boys] and 30% [girls]) with three key correlates of overfat in the main study sample.

Risk Factor(s)	Risk Factor(s) Absent			Risk Factor(s) Present		
	N	Body fat (%)	Overfat (%)	*N*	Body fat (%)	Overfat (%)
Boys						
Inactive (< 16,000 steps.day^{-1})	185	17.7 ± 0.9[a]	11.4	269	20.3 ± 0.8[b]	23.0[b]
Breakfast < 5 days	537	18.6 ± 0.5	14.7	59	21.7 ± 1.7[b]	37.3[b]
Weekday Sleep < 11 hours	297	18.3 ± 0.7	10.8	288	19.5 ± 0.8[c]	22.1[b]
Inactive + Breakfast	578	18.7 ± 0.5	15.7	24	24.6 ± 2.5[b]	50.0[b]
Breakfast + Weekday Sleep	571	18.7 ± 0.5	15.2	32	23.9 ± 2.2[b]	50.0[b]
Inactive + Weekday Sleep	466	18.3 ± 0.6	13.3	136	21.3 ± 1.1[b]	29.9[b]
Inactive + Breakfast + Weekday Sleep	588	18.7 ± 0.5	15.8	15	26.5 ± 3.2[b]	66.7[b]
Girls						
Inactive (< 13,000 steps.day^{-1})	279	21.4 ± 0.8	10.8	236	23.3 ± 0.8[b]	21.2[b]
Breakfast < 5 days	517	21.8 ± 0.6	13.2	97	24.6 ± 1.3[b]	25.8[b]
Weekday Sleep < 11 hours	351	22.3 ± 0.7	12.0	252	22.0 ± 0.9	19.0[c]
Inactive + Breakfast	580	21.9 ± 0.5	13.3	46	25.4 ± 1.9[b]	34.8[b]
Breakfast + Weekday Sleep	587	22.0 ± 0.5	13.5	39	24.4 ± 2.1[c]	35.9[b]
Inactive + Weekday Sleep	526	22.0 ± 0.6	12.5	100	23.2 ± 1.4	27.0[b]
Inactive + Breakfast + Weekday Sleep	606	22.1 ± 0.5	13.7	20	26.0 ± 2.9[b]	50.0[b]

[a]Mean ± 95% CI; adjusted for age, ethnicity, and socioeconomic status.
[b]Significantly different from Risk Factor(s) Absent group ($P < 0.01$).
[c]Significantly different from Risk Factor(s) Absent group ($P < 0.05$).

Discussion

In this study, age, ethnicity, SES, physical activity, breakfast consumption, and weekday sleep duration were identified as important predictors of overfat in New Zealand children. While these findings are generally consistent with earlier research, the specific risk factors reported by individual studies vary widely.[165] The discrepancies among studies may reflect fundamental differences between samples, such that observations made in one population may not apply to children from another. Inaccuracies in the techniques used to define childhood obesity may also contribute to the variation. The majority of previous studies have used BMI to estimate fat status. However, the relationship between existing BMI-based definitions of obesity and negative health outcomes in children is not known. Moreover, the use of BMI to classify obesity in multiethnic populations can be problematic.[58,182] The present study used a %BF-based definition of obesity to provide the first description of the correlates of excess fatness in New Zealand children.

Of the four demographic variables assessed in this study, age showed the strongest association with body fat status. This is not surprising given that children tend to accumulate body fat until they reach puberty as part of their normal physiological development.[146] When using a single %BF cut-off point for defining overfat, a natural increase in overfat participants would be expected with age. On the other hand, older children have been exposed to obesogenic factors for a longer period than younger children. It is also possible that age-related differences in the morbidity associated with body fat could confound the use of a single %BF cut-off point. Although the use of %BF percentiles would account for developmental increases in fat mass by assuming a constant level of %BF for each year of age, there are currently no %BF percentiles related to health outcomes for children. Clearly, more research is needed to establish an internationally applicable definition of excess adiposity for predicting health risk in children of all ages.

The prevalence of excess adiposity was also affected by the deprivation level of the children; those in the low SES group showed greater odds of overfat than those in the high SES group. A variety of explanations have been proposed to explain the relationship between SES and obesity. For example, individuals from lower socioeconomic regions tend to have better access to unhealthy foods and a less knowledge of healthy dietary practices than those from higher socioeconomic regions.[107] Furthermore, physical activity participation in underprivileged communities can be hindered by perceptions of unsafe neighbourhoods, limited access to gyms or sports clubs, and higher rates of sedentary activities.[252] While a number of previous studies have shown that socioeconomic factors play a role in the development of childhood obesity,[37,52,242] their impact may vary across different populations. Wang *et al*.[242] found that while American children with a low SES were more likely to be overweight than those with a high SES, the inverse relationship was observed in Brazilian children. Although ethnic variation in the relationship between SES and overfat was detected in the present sample, the general trend in all three ethnic groups was similar to that observed in other developed countries.[242]

Our initial analyses showed that the odds of overfat in Polynesian children were 2.4 greater than in European children. This is consistent with the relatively high prevalence of BMI-determined obesity previously reported in this ethnic grouping.[152,229] After adjusting for sex, age, and SES, differences in fat status between European and Polynesian children were negated. We suggest that the rates of obesity in Polynesian children may have been inflated by their overrepresentation in the 'at-risk' Low SES group. Thus, the traditional view that children of Polynesian descent are predisposed to obesity may largely reflect socioeconomic disadvantages rather than cultural or genetic influences. In contrast, Asian children maintained a significantly higher probability of overfat than European children after adjustment for differences in SES. Whether the increased risk of overfat in Asians is a consequence of fundamental differences in body composition or other social variables is currently unclear.

Several lifestyle-related factors showed significant associations with fat status. After adjustment for differences in sex, age, ethnicity, and SES, children who were not sufficiently active had more than double the odds of overfat than those who accumulated 16,000 (boys) or 13,000 (girls) steps.day^{-1}.[63] These findings support the hypothesis that physical activity is inversely related to the risk of obesity in children,[66,109,154,217] and highlight the potential advantages of pedometer-based step count targets. Many existing strategies focus on increasing the amount of time children spend on moderate to vigorous activity each day. While beneficial, this approach is less practical and harder to assess than step-based initiatives. This study provides evidence that current step count recommendations are appropriate for reducing the risk of childhood obesity across a range of age, ethnic and SES groups.

Consumption of breakfast less than five days a week was the only dietary practice assessed which increased the odds of overfat. Although several other cross-sectional studies have reported similar results in children and adolescents,[21,159,234] the mechanisms by which skipping breakfast contributes to the development of obesity remain unclear. Berkey *et al*.[16] provided evidence that the average number of calories consumed each day is greater in adolescents who regularly eat breakfast than in those who do not, suggesting that skipping breakfast does not promote fat gain through increased energy intake. It is possible that the tendency of overweight youth to skip breakfast is simply due to the high prevalence of dieting practices in this group.[21,27] In this case, reduced breakfast consumption would not be a determinant of obesity, but rather a result of the condition. To our knowledge, no studies have adjusted for differences in dieting behaviours when comparing breakfast patterns between obese and non-obese children.

The final lifestyle factor associated with fat status in this sample was sleep duration on weeknights; the odds of overfat in children who sleep less than 10 hours each weeknight were over five times greater than those who sleep at least 12 hours. This finding is in line with earlier research suggesting that inadequate sleep is an important predictor of childhood obesity.[1,37,193,240] However, the mechanisms underlying the association between sleeping patterns and body composition have yet to be elucidated. Interestingly, we found that weekend sleep duration had little effect on the risk of overfat. One hypothesis is that insufficient sleep on weekdays is more strongly related to other obesogenic lifestyle practices than weekend sleep deprivation. Although other studies reported no interactions between sleep duration and other demographic and lifestyle variables,[37,193,240] none compared weekday and weekend sleep patterns. It is also possible that biological mechanisms are responsible for the effects of short sleeping times in children. For example, a lack of sleep is often associated with reduced leptin and elevated ghrelin in adults, two key opposing hormones in appetite regulation.[200,206] Similar hormonal changes in children may result in increased food intake and thus a greater risk of obesity. Nevertheless, this theory does not explain the lack of association between weekend sleep duration and overfat in our sample.

Frequent consumption of fast food, sugary drinks, and lunch bought at school have been reported as dietary risk factors for the development of obesity in children.[14,82,85,210,235] It should be noted, however, that the results presented in previous studies were not adjusted for differences in SES. Controlling for SES (in addition to age, sex, and ethnicity) eliminated the significant associations between fat status and both fast food and sugary drink consumption in our sample. We suggest that these unhealthy dietary practices are related to SES, and contribute to the elevated risk of overfat observed in underprivileged children.[37,52,242]

A secondary objective of this study was to investigate the effects of various combinations of lifestyle risk factors on children's body fatness. Knowledge of the risk factor clusters associated with the highest body fat levels would facilitate the development of interventions tailored to those most at-risk. Danielzik *et al*.[52] showed that combining three demographic risk factors for obesity (low SES, parental overweight, high birth weight) generated the highest risk of overweight in German children. Analyses of the key lifestyle factors in the present study (inactivity, low breakfast consumption, low weekday sleep) indicated similar patterns, with the three-factor combination resulting in a greater mean %BF and prevalence of overfat than the two- or single-factor groups. Although preventative initiatives that target multiple risk factors may offer cumulative benefits, the independent effects of modifiable factors in this study also support interventions that focus on only one risk factor. In our sample, a low frequency of breakfast consumption had the greatest influence on body fatness when compared to the other two lifestyle risk factors. The impact of sedentary behaviours, such as television viewing and video games, on the interplay among the modifiable factors is another potential topic of research.

In summary, we identified several population subgroups at risk for excess fatness in New Zealand; namely older children, Asian children, and those from a low socioeconomic background. While the cross-sectional nature of this study precludes statements of cause-and-effect, our results also demonstrated a clear link between the risk of overfat and daily steps, breakfast consumption, and weekday sleep patterns, regardless of differences in sex, age, ethnicity, or SES. Furthermore, clustering of the major modifiable risk factors was associated with a cumulative increase in adiposity. Longitudinal research is required to determine the effects of these risk factors during development, including the potential implications for adult obesity. Understanding the determinants of excess fatness in young New Zealanders is essential to develop effective strategies for preventing obesity in this population.

CHAPTER 8

GENERAL DISCUSSION

Summary

The increasing prevalence of obesity around the world has highlighted a need to isolate the risk factors for excess fatness in children. Despite being one of the most important predictors of obesity, little is known about the physical activity patterns of young New Zealanders or their associations with body composition. The contribution of other demographic and lifestyle risk factors is also poorly understood. Thus, the overall aim of this thesis was to examine the key determinants of excess fatness in New Zealand children, especially with regard to physical activity. Chapters 2 to 7 represent the individual papers that were generated from three separate studies. Table 8-1 summarises Chapters 2 to 4, which relate to the use of pedometers in paediatric samples, whereas Table 8-2 describes the major findings from Chapters 5 to 7.

Chapter 2 provided the first validation data for the NL-2000 pedometer in a paediatric sample. The NL-2000 performed with similar accuracy and higher precision than the widely used SW-200 model, and was better suited for measuring steps at large pedometer tilt angles. However, pedometer performance was not related to the body composition of the children. Although both pedometer types were less effective at slow walking speeds, the significance of this finding depends on the frequency of slow walking in children during free-living activity. At present, the speeds at which children normally play are not known.

Chapter 3 investigated children’s reactivity to wearing pedometers for four 24-hour testing periods. The use of MDM pedometers enabled data collection to proceed without the need to visit children each morning to record the step count for the previous day. This new method negated the possibility of prolonged reactivity resulting from regular participant/researcher interaction. While there were no significant differences in mean steps for Periods 1 and 4 (and hence no reactivity), fewer steps were observed on Periods 2 and 3. Subsequent analysis suggested that the latter observation was due to rainfall during the time of monitoring. In addition, providing children with information about the operation and purpose of the pedometers did not affect their reactivity.

Finally, four periods of monitoring (equivalent to four days) was sufficient to obtain reliable step count estimates.

In response to the rain-reduced activity observed in Chapter 3, Chapter 4 examined the effects of a number of weather variables on both weekday and weekend step counts in children. The findings indicated that seasonal decreases in temperature (adjusted for day length) have a moderate negative effect on weekend steps in boys and a small negative effect weekday steps in both sexes. Negative effects of moderate rainfall were consistently small for both sexes and day types. In addition, the magnitudes of the temperature and precipitation effects were dependent on age and SES group. Other weather variables (day length, mean wind speed, duration of bright sunshine) had negligible effects on activity levels. It was concluded that consideration of rainfall and ambient temperature may be necessary when comparing physical activity levels across different locations or time periods. Likewise, developing physical activity options that are appropriate for cold and/or rainy days may be a priority.

Chapter 5 compared the weekday and weekend day step counts with BMI, WC, and %BF in a large multiethnic sample of New Zealand children. Results suggested that New Zealand children are relatively active, averaging more daily steps than non-representative samples of Australian and American children. The significant reduction in activity observed on weekend days indicates that increasing activity in the home environment is a priority. A significant association between steps.day^{-1} and both WC and %BF was observed, but not between steps.day^{-1} and BMI. Boys and girls with a %BF greater than the 90th percentile averaged 1,554 and 1,893 (respectively) fewer weekday steps and 1,480 and 844 fewer weekend steps than children with normal body fat levels. Although the cross-sectional study design does not allow statements of cause-and-effect, the link between steps and fatness provides some support for pedometer-based interventions designed to increase step counts in children.

Chapter 6 followed on from Chapter 5 by estimating the number of steps associated with a reduced risk of excess adiposity in children. Current BMI-referenced standards are 15,000 and 12,000 steps.day^{-1} for boys and girls, respectively.[224] Using the same analysis technique, it was found that 16,000 and 13,000 steps.day^{-1} were the best predictors of overfat, and thus existing guidelines may need to be increased by

1,000 steps.day^{-1}. Previous research suggests that this proposed increase represents a meaningful difference in children's daily activity.[224]

Chapter 7 investigated the associations between excess adiposity and a series of demographic and lifestyle variables. This represents the first assessment of the correlates of body fat in New Zealand children. Results showed that the risk of overfat increases with age and decreases with SES. Asian children were also more likely to have excess body fat when compared to European children. Accumulating less than 16,000 (boys) or 13,000 (girls) steps.day^{-1} was associated with an increase in the odds of overfat. Skipping breakfast and insufficient sleep on weekdays resulted in similar trends. Clustering of the three key lifestyle risk factors had a cumulative effect on the prevalence of overfat in this sample. This suggests that interventions focusing on only one risk factor may still provide health benefits.

Table 8-1. Summary of findings from Chapters 2-4.

Chapter	Title	Sample	Aim(s)	Summary of Findings
Chapter 2	Pedometer Validity in Children	43 boys, 42 girls 5-7 and 9-11 years	• Assess effects of age, walking speed, and body composition on pedometer performance. • Validate NL-2000 in children.	• Pedometers less accurate at slow walking speeds. • Pedometers less accurate for young children. • Confounding effect of tilt angle, but not body composition, on pedometer performance. • NL-2000 shows similar accuracy and better precision than SW-200.
Chapter 3	Pedometer Reactivity in Children	27 boys, 35 girls 5-11 years	• Investigate reactivity using pedometer that minimises participant/researcher interaction. • Determine effect of different preparatory techniques. • Determine number of monitoring periods required for reliable step count estimates.	• No reactivity to wearing pedometers, regardless of prior instruction. • Four monitoring periods sufficient for reliable step count estimates. • Physical activity was reduced by 16.4% during periods of rainfall.
Chapter 4	Weather and Pedometer Steps in Children	536 boys, 579 girls 5-12 years	• Investigate effects of selected weather variables on weekday and weekend step counts in children.	• Decrease in mean ambient temperature and moderate rainfall can have small to moderate negative effects on step counts in children. • Impact of weather on children's activity not consistent across sex, age, and SES groups.

Table 8-2. Summary of findings from Chapters 5-7.

Chapter	Title	Sample	Aim(s)	Summary of Findings
Chapter 5	Pedometer Steps and Obesity in Children	536 boys, 579 girls 5-12 years	• Investigate pedometer-determined activity in NZ European, Polynesian, and Asian children. • Examine associations among weekday and weekend step counts, BMI, WC, and %BF in children.	• NZ children relatively activity compared with overseas estimates. • Step counts significantly higher on weekdays than on weekend days. • Older children less active than younger children on weekends but not weekdays. • Step counts inversely associated with %BF and WC, but not BMI.
Chapter 6	Daily Step Count Recommendations for Children	515 boys, 454 girls 5-12 years	• Provide daily step count targets for children using %BF as the criterion reference.	• Daily step counts of 16,000 (boys) and 13,000 (girls) are associated with a reduced risk of overfat.
Chapter 7	Correlates of Obesity in New Zealand Children	603 boys, 626 girls 5-12 years	• Identify key demographic and lifestyle risk factors for overfat in New Zealand children. • Investigate the effect of risk factor clustering on overfat in children.	• Odds of overfat higher in older children, and those from Asian or low SES background. • Inactivity, skipping breakfast, and low weekday sleep increased the odds of overfat. • Clustering modifiable risk factors had cumulative effect on overfat.

Significance of Findings

During the planning phase of this thesis, it was clear that an objective measurement technique would be required to provide an accurate estimate of children's physical activity. Pedometers were the preferred option given their low cost and increasing popularity in health promotion. The recently developed NL-2000 MDM pedometer minimises the burden on researchers, and enables weekend data to be easily collected. However, the accuracy of the NL-2000 for measuring steps in children was not yet established. The results presented in Chapter 2 of this thesis represent the first validation of this new model of pedometer in a paediatric sample. The accurate and reliable performance of the NL-2000 at normal walking speeds indicates that it is an acceptable estimate of habitual activity in children. Given the considerable logistical advantages of the MDM function, it is likely that the NL-2000 or other recently developed MDM pedometers (e.g., Yamax CW-700) will become the common choice in pedometry research. The findings presented in this thesis provide support for the implementation of the NL-2000 in future studies.

Another novel finding from Chapter 2 was that pedometer tilt, but not body composition, was important with regard to both accuracy and precision. This issue has been investigated in only one previous study: Crouter *et al*.[48] showed that both tilt angle and body composition affected pedometer performance in adults. The results presented in this thesis clearly indicate that, in children, the effects of tilt angle are not related to body size. The only other explanation is that loose waistbands cause the pedometer to tilt forward, dampening the detection of vertical acceleration. This is an important consideration for physical activity researchers, as an increase in error can mask otherwise significant differences between other independent variables. It is possible that a belt system could reduce tilting in children; however the limited resources available for the three studies in this thesis did not permit the development and testing of such a system. Nonetheless, the inclusion of an elastic belt in future pedometry research is recommended to minimise the error associated with pedometer tilt.

In addition to validating the accuracy of the NL-2000, it is important to understand the reaction of children to wearing pedometers. Previous studies investigating this issue have used conventional pedometers that require researchers to visit the children each morning to record daily step counts.[163,236] The use of MDM pedometers in this thesis negated the possibility that the recurring presence of researchers results in a consistent level of reactivity in children. The subsequent findings confirm that children's activity behaviour is not affected by wearing pedometers, regardless of the preparation procedure implemented. This adds further support to the use of pedometers as a physical activity monitoring tool in paediatric populations.

While the potential dependence of children's physical activity on weather conditions is not a new concept, there is a dearth of data connecting observed changes in activity patterns with specific weather variables. The associations between daily steps and both temperature and rainfall presented in this thesis provide the only evidence that inclement weather can have detrimental effects on physical activity in young people. This leads to the conclusion that comparisons of activity levels between locations or time periods should always consider the confounding effect of weather – currently not a common practice. The development of strategies for promoting appealing activity options during cold or wet days is also recommended. Thus, the present findings have important implications for both descriptive and intervention studies in paediatric populations.

Given the priority placed on the promotion of physical activity by national health organisations, it is perhaps surprising that we know so little about the activity behaviour of young New Zealanders. The main study in this thesis has provided the only objective data describing physical activity in New Zealand children. For the first time, direct comparisons can be made with overseas studies using steps.day^{-1} as a common unit of measurement. The large reduction in steps on weekend days had not been observed previously, and is a vital development for the planning of future physical activity initiatives. Furthermore, the decrease in activity with age reported overseas appears common also to New Zealand children.

The comparison of step counts with body fatness was another aspect of this thesis that had not been formerly attempted. The only other study to investigate pedometer steps and body size in children found few associations between weekday steps and BMI.[237] The present findings suggest that an inverse relationship exists between step count and %BF, and that BMI may not be an adequate proxy measure of fatness. Subsequently, step count targets were recommended that corresponded to reduced risk of excess body fat. These guidelines are more relevant than previous estimates based on BMI, and should be valuable for promoting physical activity in children.

The primary rationale for conducting this research was to provide information that will inform future obesity prevention interventions. To date, no studies have identified the key demographic and lifestyle risk factors for excess body fat in New Zealand children. The results from this thesis suggest that Asian children are an at-risk group for the development of overfat. This was an unexpected observation given that Polynesian ethnic groups average the largest BMI values.[152] Once again, these findings highlight the potential inaccuracies that can occur when BMI is used as a substitute for body fatness. It is now apparent that Asian children should be placed alongside Polynesian children with regard to their risk of obesity.

After adjustment for demographic differences, physical inactivity, skipping breakfast, and insufficient weekday sleep were identified as key priorities for future obesity prevention programmes in New Zealand. Furthermore, the clustering of these risk factors had a cumulative effect on body fatness and the prevalence of overfat. This provides some support for smaller interventions that focus on one modifiable variable. However, improving all three risk factors should have the most beneficial outcomes.

Limitations

There are several limitations in this thesis that should be noted. To begin with, the central study in this thesis was not representative of the New Zealand population. Schools were purposively selected to reflect the socioeconomic and geographic distribution of schools in the Auckland region, and hence the results are closely representative of the Auckland population. However, given the international audience of the papers within this thesis, participants are generally referred to as 'New Zealand children'.

The main study of this thesis used a cross-sectional design to investigate childhood obesity and its determinants in a large paediatric sample. This design is limited in that the measurements for each participant were completed at one time point, and they do not provide an indication of the sequence of events. Therefore, it is not possible to ascertain if low physical activity contributes to the development of childhood obesity, or if obese children reduce their activity in response to the condition. A longitudinal study would have enabled causality to be determined, but the substantial costs and time required to implement this design in a population study were prohibitive.

The classification of participants into European, Polynesian, and Asian ethnic groups may mask significant differences within each of these groups. For example, there is evidence that South Asian adolescent boys tend to have different body builds than their East Asian counterparts.[147] On the other hand, there may also be differences within each of these two Asian groups that have yet to be researched. Given the finite number of children tested in this study, it was decided that three major ethnic groups would enable ethnic differences to be observed with sufficient statistical power.

It should also be noted that the overall chapter structure was based on a logical progression of ideas rather than the chronological order of events. Thus, the recommendations from earlier chapters are not necessarily acknowledged in later chapters. For example, Chapter 2 concluded that a belt system may reduce tilt in children with loose waistbands. This suggestion was not followed in the main study of this thesis as it was well underway by the time the preliminary validation study was conducted. Similarly, the observation that weather conditions can have small but meaningful effects on step counts in children (Chapter 4) was not addressed in Chapters 5-7, as these sections were completed and published prior to the weather-related analyses.

As mentioned in Chapter 1, the use of pedometers to measure physical activity in children has several disadvantages. First, pedometers provide an estimate of total daily activity, but are unable to record the intensity or duration of activity. Thus, compliance with traditional physical activity recommendations (i.e., 60 minutes of MVPA each day) cannot be determined. Second, the inability to detect side-to-side and upper body movement may result in the underestimation of physical activity, especially for those regularly participate in light activity. Finally, research presented in this thesis suggests that pedometers are less effective for detecting steps during slow walking, and when the pedometer is tilted away from the vertical plane. The latter issue could not be resolved for the main study in this thesis due to limited time and resources.

Future Directions

The initial stage of this thesis validated the use of NL-2000 pedometers in children. While the overall performance was acceptable, a persistent concern for both the NL-2000 and the SW-200 pedometer is the underestimation at slow walking speeds. This is not a novel finding; similar trends have been observed previously in children.[12,173] However, as there are currently no data describing the speeds at which children normally walk, it is difficult to determine the implications of speed-related error. In any case, the importance of accurately recording step counts at slow speeds is questionable given that such movement patterns are unlikely to confer significant health benefits. The development of portable global positioning systems (GPS) that can record the spatial location of individuals at high sampling rates may provide a means to better understand the movement of children during free play. The validity of pedometers for recording steps during jumping or other non-walking movement also requires investigation.

The main study in this thesis provided cross-sectional information describing obesity and its determinants in a large sample of New Zealand children. An inverse relationship between pedometer steps and body fatness was observed, suggesting that the promotion of step-based guidelines may be worthwhile. Evaluated interventions are now needed to establish the effect of increasing children's daily step counts. To date, there are no published interventions that have used pedometers to promote activity in children. Given the potential advantages over duration- and intensity-based messages, this is a research gap that needs to be addressed. In particular, the results presented in this thesis suggest that initiatives for increasing children's weekend step counts are required.

Another important aspect of this thesis was the demonstration that objective measurement tools can provide a practical means for assessing physical activity patterns in large numbers of young New Zealanders. To date, all of our nationally representative physical activity data has been obtained using subjective questionnaires that have not been validated in children. Given the high priority of physical activity promotion in many local and national strategies throughout New Zealand, it is essential that a surveillance protocol is developed to regularly and accurately monitor population trends. In this regard, utilisation of objective measures would greatly improve our knowledge of physical activity in New Zealand children. Pedometers, in particular, offer a practical and cost-effective solution, with levels of activity recorded as daily step counts. Although it is difficult to align steps.day^{-1} with the current daily targets for children of 60 minutes of MVPA,[93] it is noteworthy that these guidelines arose from general consensus among health professionals rather than evidence of positive health effects. In contrast, the recommended step counts of 16,000 (boys) and 13,000 (girls) steps.day^{-1} suggested in this thesis reflect associations between daily steps and the risk of overweight, and may therefore be more relevant to health outcomes.

In addition, there is an absence of information regarding the health risk of children at a given %BF. While the step count recommendations presented in this thesis assume that the 85th percentile of body fat represents a similar level of risk for all children, this may not be the case for all ages and ethnicities. For example, the higher mean %BF in Asian children does not necessarily correspond to an increased probability of morbidity in this ethnic group. Similarly, negative health outcomes may appear at a higher %BF in older children than in younger children (or vice versa). It is clear that we need a better understanding of the dose-response relationship between fatness and health risk in children from different demographic backgrounds.

The other lifestyle risk factors for excess body fat identified in this thesis included skipping breakfast and insufficient sleep on weekdays. Thus, interventions designed to adjust these behaviours in children are likely to be beneficial. However, longitudinal data confirming the causative effect of breakfast and sleep abnormalities on fat accretion would provide the strongest evidence for action. It would also be interesting to examine if the short sleep duration was modified by late bed times rather than early wake times. Furthermore, the interrelated changes in body fatness, physical activity, and other lifestyle behaviours that occur during development in New Zealand children could be investigated. Indeed, the implications of paediatric risk factors on obesity during adulthood are not well understood. Although such a comprehensive study would require considerable resources to implement, the potential long-term benefits for New Zealand public health are likely to outweigh the costs.

Conclusions

The results presented in this thesis represent a substantial contribution to the current body of knowledge in the area of childhood physical activity and obesity. Novel aspects include the demonstration that MDM pedometers can provide valid and reliable estimates of children's activity, and the observation that weekend activity is priority behaviour for intervention in young New Zealanders. In addition, weather conditions appear to be an important consideration when comparing activity levels across different locations or time periods. The link between high %BF and low step counts in children has not been observed elsewhere, and supports the use of pedometers in public health initiatives. The recommended step count targets resulting from this thesis correspond to an increase of 1,000 steps.day^{-1} over existing BMI-based guidelines. Finally, the cumulative increases in the prevalence of overfat with multiple lifestyle risk factors suggest that interventions focusing on only one risk factor may still impart health benefits. Overall, this thesis provides original insight into obesity and its determinants in children that will assist the development of preventative interventions.

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Appendix A: Published Journal Articles

review article

Measuring physical activity in New Zealand children: A population health perspective

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Regular physical activity in children can improve bone health, blood lipid profile, self-efficacy, and can reduce the risk of obesity and hypertension. As such, promoting an active lifestyle for young New Zealanders is a key public health priority. To ensure interventions in this area are effective, they must be founded on a clear understanding of physical activity patterns in New Zealand children. Previous national surveys of childhood physical activity have been both infrequent and subjective, based either on reports of activity from the children themselves or their caregivers. In comparison, objective measures of physical activity, such as heart rate monitoring, accelerometry, and pedometry, offer greater validity and reliability. Prospective national surveys of physical activity in New Zealand children need to place greater emphasis on obtaining objective data to establish activity patterns during both leisure- and non-leisure-time. This will assist policy-makers in developing appropriate child activity guidelines and strategies, and will enable direct comparisons with international research.

Key Words; child, heart rate, monitoring, ambulatory, New Zealand, physical activity

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Introduction

Regular physical activity can provide significant health benefits for adults, lowering the risk of all-cause mortality, cardiovascular disease, type 2 diabetes, overweight and obesity, osteoporosis, and psychological disorders such as anxiety and depression[1]. The advantages of being physically active are less clear for young people, although there is evidence that physical activity improves bone health, blood lipid profile, self-efficacy, and reduces the risk of obesity and hypertension in children[2]. Furthermore, there have been several reports of physical activity behaviour tracking into adulthood[3-6], suggesting that widespread increases in children's physical activity levels may result in long-term improvements to public health.

In spite of the potential benefits of promoting physical activity in New Zealand children, an effective strategy has yet to be established. Increasing participation in sports, while beneficial, is unlikely to reach those most at risk of inactivity. Instead, encouraging the accumulation of habitual (non-leisure time) physical activity is generally regarded as the most appropriate approach to achieve health improvements in children of all skill and fitness levels. In 1996, the US Surgeon General recommended that people of all ages participate in at least 30 min of moderate to vigorous activity (MVPA) on most, if not all, days of the week[7]. Although the current Push Play campaign co-ordinated by Sport and Recreation New Zealand (SPARC) endorses this message, not all organisations agree that this amount of activity is sufficient for young people[8,9]. Ideally, national guidelines should reflect the dose-response relationship between activity and health status in New Zealand children. However, robust physical activity data on which such guidelines can be based are scarce. The intention of this review is to provide the information necessary to resolve this problem. More specifically, we will (1) evaluate current knowledge of childhood physical activity in New Zealand, (2) discuss the advantages and disadvantages of several objective techniques for estimating physical activity in paediatric populations, and (3) provide appropriate recommendations for future physical activity research in New Zealand children.

Physical activity in New Zealand children – what do we know?

Compared with other developed countries, New Zealand is considered an active nation[10]. Despite this, less than half of the adult population are achieving the recommended 30 minutes of physical activity on five or more days of the week[11]. Several large-scale surveys have been conducted over the last 15 years to investigate this issue in New Zealand children.

The first national study to include childhood physical activity was the Life in New Zealand (LINZ) survey co-ordinated by the University of Otago during the late 1980s[12]. From this dataset, it was estimated that 80% of New Zealand children aged 5-15 years participate in some form of regular physical activity. While the adult physical activity questionnaire used in the LINZ survey correlated reasonably well with other subjective and objective measures[13], information on children's physical activity was gathered using a non-validated proxy-report (the estimation of participants' behaviour by a third party). This tool is commonly used with young children to avoid the recall errors associated with self-report questionnaires. Although practical and cost-effective, not all proxy-report questionnaires show acceptable validity in estimating physical activity[14]. Response accuracy is highly dependent on the type of information assessed, with reports on unchanging physical characteristics achieving greater precision than reports of subjective behaviours such as physical activity[15]. Furthermore, there is evidence that the characteristics of the proxy respondent can significantly affect recall of a child's health status[16]. Until validated, it is not possible to establish the accuracy of the physical activity data obtained using the LINZ proxy-report.

More recent information on the activity levels of New Zealand children was provided by three Hillary Commission/SPARC Sport and Physical Activity Surveys conducted between 1997 and 2001[10]. Physical activity levels over the preceding two weeks were estimated *via* a phone interview with a 'random adult' respondent in the same household. Averaged results from all three surveys indicate that 68% of New Zealanders aged 5-17 years undertake at least 2.5 hours of sport or active leisure each week. In addition to the conventional problems associated with non-validated proxy-reports, it is likely that the accuracy of this particular system is dependent on the closeness of the relationship between the child and the respondent. However, the greatest shortcoming of the Sport and Physical Activity Surveys is the lack of data describing habitual physical activity in children.

In 2002, the Children's Nutrition Survey (CNS) was conducted as a Ministry of Health initiative by researchers from Auckland, Massey (Palmerston North) and Otago Universities[17]. Physical activity patterns of 5-14-year-old children were evaluated using the Physical Activity Questionnaire for Older Children (PAQ-C) self-report protocol[18]. Although this study expanded on the Sport and Physical Activity Surveys by incorporating habitual activity, the appropriateness of the PAQ-C for assessing the activity of young children is questionable. Correlation between the PAQ-C and accelerometry in children aged 9-14 years is relatively weak (r = 0.39)[19], with no validation data available for younger children. Indeed, self-report techniques are generally avoided in those less than 10 years of age due to the inability of young children to accurately recall their behaviour[20]. In any case, data quantifying physical activity duration and intensity were not collected, making it difficult to apply international standards to the CNS results.

Objective measures of childhood physical activity

Overall, there is a clear need to improve on the methodology of our previous national surveys of childhood physical activity. A wide range of objective measures are available for assessing physical activity levels, each of which has clear advantages over subjective reports. Although direct observation is considered the 'gold standard' in children, the considerable time and effort required to implement this technique precludes its use in population research. Similarly, the doubly labelled water method offers a high level of validity and reliability, but is impractical on a large scale due to the high cost and time-consuming preparation and analysis procedures. The three major objective tools used to gather childhood physical activity data in overseas population studies are heart rate (HR) monitors, accelerometers, and pedometers.

HR Monitors

HR monitors are often used in health research to provide real-time estimates of energy expenditure (EE) during children's natural activities. A transmitter belt worn around the chest detects electrical activity from the heart and sends an electromagnetic signal to the receiver attached to the wrist. These HR data can be stored for future analysis, and provide a good indication of both EE intensity and duration over the test period. Although an indirect estimate of physical activity, HR monitoring has been validated with oxygen consumption (VO_2) in children during non-regulated play activity[21], and with direct observation during high-level activity[22]. However, it has been suggested that the delayed reaction of HR in response to both the onset and cessation of movement may cause the sporadic activity patterns common in children to be missed[23].

Several different methods have been devised to estimate physical activity level from HR data. A conventional technique is to determine the amount of time each participant spends above a predetermined HR. One New Zealand study used a threshold of HR ≥ 140 bpm to represent MVPA, and found that only 32 out of 60 Christchurch children aged 10-13 years were achieving at least 30 min of MVPA on three out of four days[24]. This threshold was based on earlier research that reported a mean HR of 140 bpm during brisk walking from a sample of 98 children aged 5-16 years[25]. Although straightforward, this method suffers from a large degree of misclassification due to the substantial variance in fitness levels among participants. An alternative procedure is to measure the amount of time spent above a given percentage of resting heart rate (RHR). This technique controls for variation in fitness levels between participants, however the protocol used to define RHR has a considerable effect on estimates of childhood physical activity. Indeed, Logan *et al.*[26] demonstrated that time spent at a HR greater than 50% of RHR can vary by 16-65% depending on the interpretation of RHR. Until the definition of RHR is standardised, it is difficult to make valid comparisons between studies using this method.

Further problems with the HR method arise when activity decreases in intensity, and factors other than body movement exert a significant effect on HR (e.g., ambient temperature, hydration levels, emotional stress). In these instances, HR cannot be used to estimate activity status with a sufficient degree of accuracy. To overcome this problem, several studies have used regression equations individualising the HR-VO_2 relationship for each child to establish a 'FLEX HR' point that falls between 'resting' and 'active' HR. For periods above the FLEX HR a linear HR-VO_2 relationship is assumed; below the FLEX HR the predetermined resting metabolic rate is used. Estimates of children's EE using this technique have shown a relatively high degree of within-subject variability when compared with doubly labelled water[27,28] and indirect calorimetry[28,29], with especially poor results in obese children[30]. One explanation for this variability is differences in the types of activity performed by the children during FLEX HR calibration and during the testing period. These differences may be largely unavoidable given that the simulation of a wide range of activities during calibration imposes an excessive burden on children[31]. Treuth *et al.*[32] found that predetermining two HR-VO_2 relationships (one 'active' and one 'inactive') by using accelerometers to determine activity status could increase the accuracy of EE prediction from HR in a small sample of American children (N = 20). However, further testing is required for this method to be considered valid for use in large-scale research.

Of additional concern when using HR monitors is the 60 s sampling period required by most models to enable data collection to be sustained over several days. This is a potential source of error given that intermittent activity patterns lasting

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less than 60 s may be missed. The most problematic issues, however, may be participant interference with the monitors, incorrect repositioning of transmitter belts by children and caregivers, and the use of transmitters that cannot be correctly fitted to children's chests. The recently released Polar Wearlink soft transmitter belts are designed to be highly flexible and may be better suited for use with children. Nevertheless, children tend to find chest belts uncomfortable to wear for extended periods[33], and, as such, participant non-compliance may remain a concern in physical activity studies. The cost of HR monitors that are able to store several days of data (approximately NZ$650 each) is another factor that may limit the appeal of this technique for population research.

Accelerometers

Accelerometers are smaller and much less obtrusive than HR monitors, and have been used extensively in overseas studies to measure physical activity in children. Accelerometers use piezoelectric transducers and microprocessors to convert accelerations of the body into activity 'counts', with more vigorous movement resulting in a greater number of counts. Thus, both frequency and intensity of activity over a test period can be stored for later analysis, enabling participants who do not undertake the recommended amount of MVPA to be easily identified. It appears that at least five days of monitoring by accelerometry are required to obtain an acceptable estimate of physical activity in children[34].

There is a range of accelerometers of varying reliability and validity. Of these, Computer Science and Applications (CSA), Tritrac-R3D, and Actiwatch accelerometers correspond well with higher standards of physical activity in children[25,35,36]. The CSA accelerometers are undoubtedly the most established in child health research. Recent models feature water-resistant casing, increasing the range of activities that can be monitored. Actiwatch accelerometers are also water-resistant, and have the added benefit of a digital integration data acquisition system that automatically determines intensity level. Initial comparisons with room respiration calorimetry and HR in children have shown promising results, with Actiwatch accelerometers performing slightly better than their CSA counterparts[36]. The increased accuracy of the Actiwatch accelerometer may be attributed to its omnidirectional measurement capability – CSA accelerometers are restricted to recording movement in the vertical plane.

Despite the benefits of using accelerometers in field studies of physical activity, there are several significant shortcomings. The first is cost – accelerometers start at approximately NZ$500 each, with some systems requiring the purchase of supplementary hardware and/or software. This factor alone may rule out the use of accelerometers in some large-scale surveys. The second drawback is that upper body movement, load carriage, or terrain changes may not be detected as accurately as other activities[36]. CSA accelerometers also appear to have difficulty distinguishing between different running velocities[37]. Nevertheless, accelerometry is generally regarded as the most effective technique for quantifying physical activity in paediatric populations.

Pedometers

Pedometers are a cheaper alternative to accelerometers and as a result are widely used in field-based studies of physical activity. Similar in size to accelerometers, they can be purchased for as little as NZ$40 each and are worn on the waistline to record the number of steps taken each day. Of the various pedometer models, the Yamax Digiwalker series is the most accurate at recording steps and distance in adults[36]. In children, Eston *et al.*[21] found that steps recorded during play using the Digiwalker SW-200 were relatively consistent with VO_2 and HR. A similar study by Kilanowski *et al.*[39] showed high correlations between the SW-200 and both the Tritrac-R3D accelerometer and direct observation during children's recreational physical activity. Such findings have established the Yamax Digiwalker series as the most popular pedometers for estimating physical activity in children. More recently, the New Lifestyles NL-2000 pedometer was released featuring an internal clock that can categorise data according to the day of the week for up to seven days, thereby removing the need for researchers to collect data each day of the test period. Although yet to be validated in children, the NL-2000 appears to be one of the most accurate pedometers for measuring steps in adults[36].

The major disadvantage of utilising pedometers in physical activity research is that they are unable to provide an indication of the frequency or intensity of activity. Scruggs *et al.*[40] overcame the latter during a 30-minute physical education lesson by comparing steps.min^{-1} with time spent in MVPA (assessed *via* direct observation). This enabled the derivation of steps.min^{-1} benchmarks that corresponded to a specific percentage of class-time in MVPA. However, applying this methodology to free-living children over an entire day would be costly, time-consuming, and ultimately impractical.

Another drawback of using pedometers to measure activity is the reduction in sensitivity during low-intensity activity, possibly due to the inability to detect side-to-side and upper body movement[21]. This may result in an underestimation of physical activity, especially in sedentary children who spend a higher proportion of time in a low-activity state. It has also been suggested that excessive body fat around the waist in overweight individuals may tilt pedometers to an angle at which precision is reduced. Although there is evidence both for[41,42] and against[43] this hypothesis in adults, the association between body size and pedometer validity in children is unknown. The accuracy of pedometers for detecting children's steps at various walking speeds is another issue yet to be investigated.

In spite of these potential shortcomings, there are obvious advantages to quantifying physical activity by pedometry. Increasing total number of steps per day is a relatively straightforward concept to understand, and the active feedback provided by the pedometer can serve as a motivating factor. The implementation of steps per day as a general physical activity 'currency' will facilitate comparisons between children, adolescents, and adults from various populations. Already, the use of adult physical activity guidelines based on a recommended daily step count has proven successful in overseas studies[44], and is currently in development as a public health intervention for the Northland province of New Zealand. However, the number of daily steps required for health benefits in children is still a matter of debate. It appears that most children are achieving between 10,000 and 16,000 steps per day, with boys more active than girls[33,45]. Tudor-Locke *et al.*[46] recently proposed daily step count 'cut points' of 12,000 for girls and 15,000 for boys based on reducing the probability of overweight and obesity (defined using international age- and gender-specific Body Mass Index [weight.height^{-2}] thresholds[47]). Further research is needed to establish minimum daily step counts that will preclude other health problems associated with inactivity.

Future Directions

Promoting regular physical activity in children is a key priority for New Zealand. Thus, it is vital that both leisure- and non-leisure-time activity patterns of this population are well understood. Despite this, the use of subjective techniques to approximate the number of children achieving a pre-determined level of physical activity remains standard practice for large-scale surveys in New Zealand. SPARC is presently in the process of testing an updated Sport and Physical Activity Survey that will assess the duration and intensity of all forms of activity in adults. It is envisaged that a similar questionnaire will be developed for children and adolescents, which should provide more accurate information than previous surveys. Nevertheless, there remains substantial evidence questioning the validity and reliability of subjective methods in young children[14,16,20]. Objective measures of activity, such as accelerometry, pedometry, and HR monitoring, are able to quantify physical activity with a higher degree of precision without relying on controversial overseas guidelines. A shift to these techniques may provide a more accurate and universal description of physical activity in young New Zealanders. Moreover, collecting valid, objective physical activity data in a nationally representative study of child health such as the CNS can be a relatively inexpensive process.

One study in progress that may provide a more accurate picture of physical activity in New Zealand children is the Ministry of Education's Primary Schools Physical Activity Project (PSPAP). The PSPAP will utilise HR monitors (Polar S610*i*) to estimate activity in children from Auckland and Christchurch *via* the duration and intensity of EE over a seven-day period. The Auckland University of Technology is also conducting the Body-size and Steps in Children Study (BASIC) that will assess the number of pedometer steps a sample of 1200 Auckland children accumulate each day. These studies will present an opportunity to assess the relevance of previous survey results. Furthermore, the implementation of objective tools to assess childhood physical activity will reduce our reliance on subjective questionnaires and interviews, ensuring that future initiatives are based on a thorough understanding of physical activity in New Zealand children.

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Effects of Age, Walking Speed, and Body Composition on Pedometer Accuracy in Children

J. Scott Duncan, Grant Schofield, Elizabeth K. Duncan, and Erica A. Hinckson

The objective of this study was to investigate the effects of age group, walking speed, and body composition on the accuracy of pedometer-determined step counts in children. Eighty-five participants (43 boys, 42 girls), ages 5–7 and 9–11 years, walked on a treadmill for two-minute bouts at speeds of 42, 66, and 90 m•min^{-1} while wearing a spring-levered (Yamax SW-200) and a piezoelectric (New Lifestyles NL-2000) pedometer. The number of steps taken during each bout was also recorded using a hand counter. Body mass index (BMI) was calculated from height and mass, and percentage of body fat (%BF) was determined using hand-to-foot bioelectrical impedance analysis. The tilt angle of the pedometer was assessed using a magnetic protractor. Both pedometers performed well at 66 and 90 m•min^{-1}, but undercounted steps by approximately 20% at 42 m•min^{-1}. Although age group, BMI, waist circumference, and %BF did not affect pedometer accuracy, children with large pedometer tilt angles (≥ 10°) showed significantly greater percent bias than those with small tilt angles (< 10°). We suggest that the style of waistband on the child's clothing is a more important determinant of tilt angle and thus pedometer accuracy than body composition. Our results also indicate that the NL-2000 pedometer provides similar accuracy and better precision than the SW-200 pedometer, especially in children with large tilt angles. We conclude that fastening pedometers to a firm elastic belt may improve stability and reduce undercounting in young people.

Key words: measurement, pediatric, physical activity, step counts

Widespread increases in childhood overweight and obesity have triggered an upsurge in the promotion of physical activity in young people. In this regard, the use of pedometers to monitor daily step counts offers several advantages over traditional strategies based on time spent in moderate to vigorous physical activity. Increasing the number of steps accumulated each day is a straightforward concept to understand and is nonthreatening for children of all body sizes and physical abilities. For researchers, pedometers provide an objective and cost-effective measure of children's activity that can be easily compared across study populations and time periods. In recent years, a growing number of studies have used pedometers to provide cross-sectional physical activity data (Duncan, Schofield, & Duncan, 2006; Vincent, Pangrazi, Raustorp, Michaud Tomson, & Cuddihy, 2003) and to evaluate activity interventions in children (Pangrazi, Beighle, Vehige, & Vack, 2003; Schofield, Mummery, & Schofield, 2005).

While unable to measure the intensity, frequency, or duration of activity, pedometers provide estimates of overall activity that correlate well with accelerometers (Kilanowski, Consalvi, & Epstein, 1999), heart rate monitors (Eston, Rowlands, & Ingledew, 1998), and observational techniques (Scruggs et al., 2003). However, only two studies have investigated the validity of pedometers for measuring children's steps in a controlled setting. Ramírez-Marrero, Smith, Kirby, Leenders, and Sherman (2002) compared the step counts recorded by a Yamax Digiwalker SW-200 pedometer with observed steps during 2 min of treadmill walking. Their results indicate that the SW-200 performs accurately at speeds of 70 and 90 m•min^{-1}, but underestimates steps by an average of 12.9% at a speed of 58 m•min^{-1}. Beets,

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Patton, and Edwards (2005) conducted a similar study examining the accuracy of the SW-200 pedometer along with three other models: the Walk4Life 2505, the Sun TrekLINQ, and the Yamax Digiwalker SW-701. When compared with observed steps, the mean percent bias of all four pedometers was significant at slow walking speeds of 40 and 54 $m \cdot min^{-1}$.

The accuracy of pedometers at different walking speeds may also depend on the age of the child. At present, no data describe differences in pedometer error between age groups. Biokinetic research suggests that children ages 5–6 years adopt walking features distinct from those ages 7–12 years (Jeng, Liao, Lai, & Hou, 1997). Young children showed greater variability in intra-limb coordination and more difficulty maintaining symmetry when compared with older children, who demonstrated a mature walking form similar to that observed in adults. Not surprisingly, young children also produce less ground reaction force (GRF) than older children due to their lighter mass (Takegami, 1992). It is possible that these factors may contribute to age-specific variation in the measurement bias associated with pedometers.

The potential effects of body size on pedometer accuracy add another layer of complexity. It has been proposed that excess abdominal adiposity in some individuals may reduce the ability of pedometers to detect steps by obstructing correct placement on the waistline or by dampening vertical accelerations of the body (Tudor-Locke, Williams, Reis, & Pluto, 2002). In adults, a positive association between body mass index (BMI) and pedometer bias was observed by Melanson et al. (2004) and Shepherd, Toloza, McClung, and Schmalzried (1999), but not by Swartz, Bassett, Moore, Thompson, and Strath (2003). More recently, Crouter, Schneider, and Bassett (2005) concluded that the effects of both BMI and waist circumference (WC) were less important than tilt angle with regard to the measurement error of SW-200 pedometers in obese adults. The latter authors hypothesized that increased friction on the spring-suspended lever arm, due to tilt away from the vertical plane, may lead to the underestimation of steps. Indeed, the authors noted that the accuracy of a pedometer that operates via a piezoelectric strain gauge (New Lifestyles NL-2000) was not affected by tilt angle. To date, no studies have investigated the associations among pedometer accuracy, body size, and tilt angle in young people for spring-levered or piezoelectric pedometers.

In addition to a piezoelectric mechanism, the NL-2000 offers an advantage over conventional pedometers (such as the SW-200) with its multiday memory (MDM) function that automatically categorizes data according to the day of the week. This removes the need for researchers to visit participants each morning to record the steps for the previous day, enabling step count data for both weekdays and weekends to be collected without difficulty (Duncan et al., 2006). Despite these technical advancements, the ability of the NL 2000 pedometer to estimate steps in children has yet to be assessed.

It is clear that there are several potential sources of measurement error in pedometer-determined physical activity yet to be explored in a pediatric sample. The purpose of this study was to determine the effects of children's walking speed, age, and body composition on pedometer accuracy and precision. A secondary objective was to compare the performance of a spring-levered (SW-200) and a piezoelectric (NL-2000) pedometer for recording steps in children.

Method

Participants

A total of 85 children (43 boys, 42 girls) were selected from a primary (elementary) school in Auckland, New Zealand. The sample was composed of two distinct age groups: those from Years 1 and 2 (5–7 years; 42.4%) and those from Years 5 and 6 (9–11 years; 57.6%). The ethnic composition of the sample was 43.5% Caucasian, 32.9% Asian, 12.9% Polynesian, and 10.6% from other ethnicities. Each participant and his or her legal guardian gave written informed consent. Ethical approval for this study was obtained from the institutional ethics committee.

Body Composition Measurements

The height and mass of each participant was measured using a portable stadiometer (Design No. 1013522, Surgical and Medical Products, Seven Hills, Australia) and a digital scale (Model Seca 770, Seca, Hamburg, Germany). BMI was calculated as mass (kg) divided by squared height (m^2). WC measurements were made at the highest point of the iliac crest at minimal respiration. Resistance (R) measurements were obtained at 50 kHz using a bioimpedance analyzer (Model BIM4, Impedimed, Capalaba, Australia) with a tetrapolar arrangement of self-adhesive electrodes (Red Dot 2330, 3M Healthcare, St Paul, MN). Participants were asked to empty their bladder before lying supine with their arms and legs abducted. Testing continued until measurements of R were within 1 ohm of each other. A prediction equation previously validated in New Zealand children (Rush, Puniani, Valencia, Davies, & Plank, 2003) was used to obtain estimates of fat-free mass and fat mass from height, mass, and R values. Percentage body fat (%BF) was then calculated as the ratio of fat mass to mass multiplied by 100.

Pedometer and Treadmill Procedures

The accuracy of the Yamax Digiwalker SW-200 (Yamax Corp., Tokyo, Japan) and New Lifestyles NL-2000 pedometers (New Lifestyles Inc., Lee's Summit, MO) were assessed in this study. To ensure representative results, five units of each model were tested (10 in total). Prior to use, all pedometers were checked for faults using five repetitions of the 100-step walking test described by Vincent and Sidman (2003). This process was repeated once during testing and once following the completion of data collection. Absolute error was no more than two steps (2%) for each of the 10 pedometers tested.

Each participant was asked to walk normally on a treadmill (Accumil-P, Pacer Fitness Systems Inc., Irving, TX) for three bouts of two minutes. The treadmill speed was set to 42 $m \cdot min^{-1}$ for the first bout, 66 $m \cdot min^{-1}$ for the second bout, and 90 $m \cdot min^{-1}$ for the third bout. These speeds were selected to simulate slow, moderate, and fast walking in children. The treadmill was initially calibrated by measuring the belt length and the time taken to complete 30 revolutions at the lowest and highest testing speeds. The gradient was set to 1% to replicate normal walking conditions (Jones & Doust, 1996). After becoming familiar with walking on the treadmill, participants placed their feet on each side of the belt while a SW 200 and a NL 2000 pedometer was fastened to the waistband of their clothing at the anterior midline of the right and left thigh. The placement of the pedometers was randomized for each participant so that both models were tested on right and left sides. At the completion of each bout, participants were instructed to straddle the treadmill while pedometer steps were noted and the pedometer was reset to zero. A researcher using a hand counter also recorded the number of steps accumulated in each bout. Pedometer tilt angles were measured pre- and posttest using a magnetic protractor (Empire Level Manufacturing Corp., Mukwonago, WI) while standing normally next to the treadmill, with the average of the two measurements used in subsequent analyses. A positive angle indicated that the top of the pedometer tilted away from the body, whereas a negative angle denoted a tilt toward the body.

Statistical Analyses

All data were analyzed using SPSS version 14.0 for Windows (SPSS Inc., Chicago, IL) and a p value less than 0.05 to indicate statistical significance. Descriptive statistics were generated for age, height, mass, BMI, WC, and %BF, and were expressed as means and standard deviations. Differences among sex and age groups were examined using independent samples t tests. Bias (pedometer steps - observed steps) was converted to a percentage of observed steps to assess the relative under- or overestimation of pedometer steps for each model. A negative percent bias indicates undercounting, while a positive percent bias indicates overcounting. The 95% limits of agreement and loss of precision statistics were also calculated to provide an indication of reliability. The loss of precision, or the variance of prediction error divided by the variance of the criterion value, measures the theoretical increase in sample size required to offset the prediction error (Fleiss, 1986). The consistency of percent bias at the extremes of the observed step-count distribution was investigated using correlation analysis. For example, a significant correlation between the observed steps and the percent bias would indicate that the relative error associated with pedometers varies with the number of steps taken.

To identify the variables associated with percent bias for each pedometer type, sex, age group (Years 1–2 and Years 5–6), and speed (42, 66, and 90 $m \cdot min^{-1}$) were entered into a $2 \times 2 \times 3$ factorial repeated measures analysis of variance (ANOVA; Sex x Age Group x Speed). BMI, WC, %BF, and pedometer tilt angle were added into the model separately as covariates. Based on the tilt angle categories used in previous research (Crouter et al., 2005), participants were divided into small tilt angle (< 10°) and large tilt angle (≥ 10°) groups. Modified Bland-Altman plots were then generated for both models to demonstrate the effects of pedometer tilt on the mean percent bias and 95% prediction interval. The observed step counts were used on the x-axes (rather than the mean of the observed and pedometer step count), given the negligible error associated with this measure.

Results

Table 1 shows the physical characteristics of the study sample. In general, children ages 9–11 years were taller and heavier, with a larger BMI, WC, and %BF than children ages 5–7 years ($p < .01$). Two exceptions were the 1.4 $kg \cdot m^{-2}$ difference in BMI ($p = .190$) and the 2.5% difference in %BF ($p = .223$) between younger and older girls. The only significant difference between sexes was a 4.3% higher %BF in 5–7-year-old girls when compared with boys of the same age ($p = .016$). Based on international age- and sex-specific BMI cut-off points (Cole, Bellizzi, Flegal, & Dietz, 2000), 19.0% (boys) and 20.0% (girls) of participants were classified as overweight, while a further 7.1% and 10.0%, respectively, were obese.

The relationships between the observed and measured step counts for the SW-200 and NL 2000 pedometers are presented in Table 2. The overall performance of the two pedometers was similar, with both models underestimating steps during slow and moderate walking (42 and 66 $m \cdot min^{-1}$). Slow walking, in particular, resulted in high percent bias and 95% limits of agreement. The mean percent biases produced during moderate walking were smaller; however, the limits of agreement remained relatively high. Although only the SW 200 pedometer achieved a percent bias statistically equivalent to zero during fast walking, both models performed adequately at this speed. The positive correlations between observed steps and percent bias at slow and moderate walking speeds indicate that the underestimation was greatest for participants who accumulated the fewest number of steps during the measurement periods. The loss of precision was relatively high at slow and moderate speeds, with smaller values for the NL-2000 than the SW-200 pedometer. There was no significant difference in percent bias between the SW 200 (8.6 ± 14.7%) and the NL 2000 (8.5 ± 13.3%) pedometer when data from all three speeds were combined (p = .855). Furthermore, a positive correlation in mean percent

Table 1. Participant characteristics

	5–7 years				9–11 years			
	Boys (n = 17)		Girls (n =19)		Boys (n = 26)		Girls (n = 23)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Age (years)	6.0	0.5	6.2	0.7	9.9	0.6	10.1	0.7
Height (cm)	116.8	8.1	116.1	6.3	141.0	7.5	140.7	6.0
Mass (kg)	22.4	4.4	23.6	7.5	38.2	9.1	36.9	6.2
Body mass index (kg.m^{-2})	16.3	1.5	17.2	3.6	19.1	3.5	18.6	2.8
Waist circumference (cm)	53.5	4.7	53.3	7.5	63.7	9.0	62.1	6.8
Body fat (%)	16.5	3.4	20.8	5.8	22.1	6.9	23.3	6.1

Note. *M* = mean; *SD* = standard deviation.

Table 2. Validation of SW-200 and NL-2000 pedometers for measuring steps at 42, 66, and 90 m•min^{-1} in children ages 5–11 years

Speed	Difference in steps[a]		$r_{y,y'}$[b]	Mean percent bias (%)[c]	p[d]	Proportion of over- and undercounting (%)	$r_{y,\%bias}$[e]	95% limits of agreement (%)[f]	Loss of precision (%)[g]
	M	*SD*							
SW-200									
42 m•min^{-1}	-44.6	40.9	.708	-20.1	0.000	3.5/3.5/92.9[h]	.213	-57.7, 17.5	108.8
66 m•min^{-1}	-13.2	20.7	.875	-5.2	0.000	27.1/5.9/67.1	(p = .051)	-21.1, 10.7	35.0
90 m•min^{-1}	-2.1	9.4	.964	-0.7	0.061	49.4/11.8/38.8	.181 (p = .097) -.084 (p = .445)	-7.3, 5.9	7.1
NL-2000									
42 m•min^{-1}	-45.0	32.2	.813	-20.6	0.000	2.4/1.2/96.5	.362	-52.5, 11.3	67.4
66 m•min^{-1}	-11.4	14.7	.935	-4.5	0.000	11.8/11.8/76.5	(p = .001)	-16.3, 7.3	17.5
90 m•min^{-1}	-1.7	5.8	.987	-0.5	0.019	40.0/10.6/49.4	.298 (p = .006) -.270 (p = .013)	-4.2, 3.2	2.7

Note. *M* = mean; *SD* = standard deviation.
[a]Difference in steps = pedometer steps - observed steps.
[b]Correlation coefficient between observed steps and pedometer steps.
[c]Percent bias = ([pedometer steps - observed steps]/observed steps) × 100.
[d]Probability that mean percent bias = 0.
[e]Correlation coefficient between the observed steps and the percent bias.
[f]95% limits of agreement = mean percent bias ± 1.96 × percent bias SD.
[g]Loss of precision = ([variance of pedometer steps - observed steps]/variance of observed steps) × 100.
[h]Overcounting/exact counting/undercounting.

bias between pedometers was detected ($r = .745$, $p < .001$), suggesting that children tend to have similar bias levels for each model.

To determine the factors associated with the percent bias at each of the three walking speeds, a factorial repeated measures ANOVA (Sex x Age Group x Speed) was conducted for each pedometer type. Associations between percent bias and walking speeds were observed (SW 200, $F = 91.915$, $p < .001$; NL-2000, $F = 123.770$, $p < .001$), with significant interactions between speed and age group for the NL 2000 pedometer ($F = 8.653$, $p < .001$), and between speed and sex for both pedometer models (SW 200, $F = 3.688$, $p = .027$; NL 2000, $F = 4.542$, $p = .012$). In other words, the data indicate that the reduction in mean percent bias with increasing speeds varies with sex (and age group in the NL 2000). Overall, boys averaged 5.4% (SW-200, $F = 7.317$, $p = .008$) and 3.4% (NL-2000, $F = 5.256$, $p = .024$) less bias than girls. Sex-specific differences in percent bias were significant for all walking speeds in the SW 200 (slow, 9.1%, $t = 2.235$, $p = .028$; moderate, 4.4%, $t = 2.580$, $p = .012$; fast, 1.9%, $t = 2.675$, $p = .010$) and only at slow walking speeds in the NL-2000 (7.1%, $t = 2.050$, $p = 0.044$; see Figure 1). Although mean percent bias was 2.8% (SW 200) and 4.1% (NL 2000) higher in older children than in younger children, the difference was significant for the NL 2000 only ($F = 7.803$, $p = .007$). Age-specific differences in the NL-2000 bias were significant during slow (9.6%, $t = 3.034$, $p = .003$) and moderate (2.7%, $t = 2.184$, $p = .032$) walking, but not during fast (0.5%, $t = -1.249$, $p = .215$) walking (see Figure 2).

No significant associations were detected between percent bias and BMI, WC, or %BF when added separately as covariates to the repeated measures ANOVA (Sex x Age Group x Speed). However, pedometer tilt angle was associated with mean percent bias for both pedometers (SW 200, $F = 22.689$, $p < .001$; NL-2000, $F = 6.310$, $p = .014$). Adjusting for tilt angle did not negate the significant difference in mean percent bias between sexes (SW 200, $F = 11.516$, $p = .001$; NL-2000, $F = 6.276$, $p = .014$) or between age groups for the NL 2000 ($F = 8.690$, $p = .004$). However, no significant interactions were detected between tilt angle and sex (SW-200, $F = 0.002$, $p = .961$; NL-2000, $F = 0.519$, $p = .474$) or between tilt angle and age group (SW-200, $F = 0.277$, $p = .600$; NL-2000, $F = 0.002$, $p = .962$). Further analysis revealed significant partial correlation coefficients between percent bias and tilt angle (controlled for sex, age, BMI, WC, and %BF) for the SW 200 pedometer at slow ($r = .465$), moderate ($r = .506$), and fast ($r = .404$) walking speeds ($p < .001$ for all). These results suggest that tilt angle has a significant effect on SW-200 error regardless of sex, age, walking speed, or body composition. Similar results were obtained for the NL-2000 pedometer at slow ($r = -0.298$; $p = .009$) and moderate speeds ($r = 0.258$; $p = 0.025$), but not at fast speeds ($r = -0.010$; $p = .935$).

Figures 3 and 4 show the effects of tilt angle on the percent bias of both pedometers at all three measurement speeds. In total, 35.7% and 39.3% of the sample had large (≥ 10°) tilt angles when wearing SW-200 and NL-2000 pedometers, respectively. For the SW-200 pedometer, percent bias increased from 5.5 ± 11.5% in children with small (< 10°) tilt angles to 14.1 ± 18.0% in children with

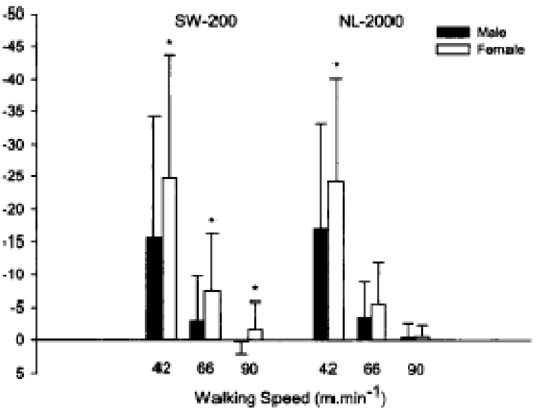

Figure 1. Percent bias of SW-200 and NL-2000 pedometers for boys and girls walking at 42, 66, and 90 m•min^{-1}. Data are expressed as means and standard deviations. Note: * = significant difference from male ($p < .05$).

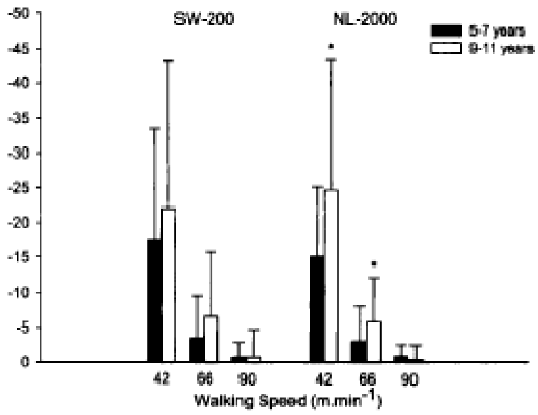

Figure 2. Percent bias of SW-200 and NL-2000 pedometers for children ages 5–7 years and 9–11 years walking at 42, 66, and 90 m•min^{-1}. Data are expressed as means and standard deviations. Note: * = significant difference from 5–7 years ($p < .05$.

large tilt angles ($t = 4.110$, $p < .001$). Differences between small and large tilt angle groups were less pronounced for the NL-2000 pedometer, with percent bias increasing from 7.1 ± 12.1% to 10.7 ± 14.7%, respectively (t = 2.055, p = .041). A large tilt angle also resulted in wider 95% prediction intervals, particularly for the SW-200 pedometer. Additional analyses (not shown) revealed that this reduction in precision was independent of sex or age group for both pedometers.

Discussion

In this study, we investigated the effects of walking speed, age group, and body composition on the accuracy of two types of pedometer for measuring steps in children. The results show that spring-levered (SW-200) and piezoelectric (NL-2000) pedometers provide acceptable estimates of step count during moderate and fast walking, but undercount steps by approximately 20% at a slow walking speed. This is consistent with the 15–30% underestimation previously observed for the SW-200 during slow walking in both children (Beets et al., 2005; Ramírez-Marrero et al., 2002) and adults (Crouter et al., 2005; Le Masurier, Lee, & Tudor-Locke, 2004; Swartz et al., 2003), and it suggests that the vertical acceleration forces generated during slow walking frequently fall below the 0.35 g required to register a step in the pedometers tested. Furthermore, the associations between the percent bias and observed steps at slow and moderate speeds indicate that the degree of underestimation decreased with the number of steps taken. A possible explanation for this result is that children who

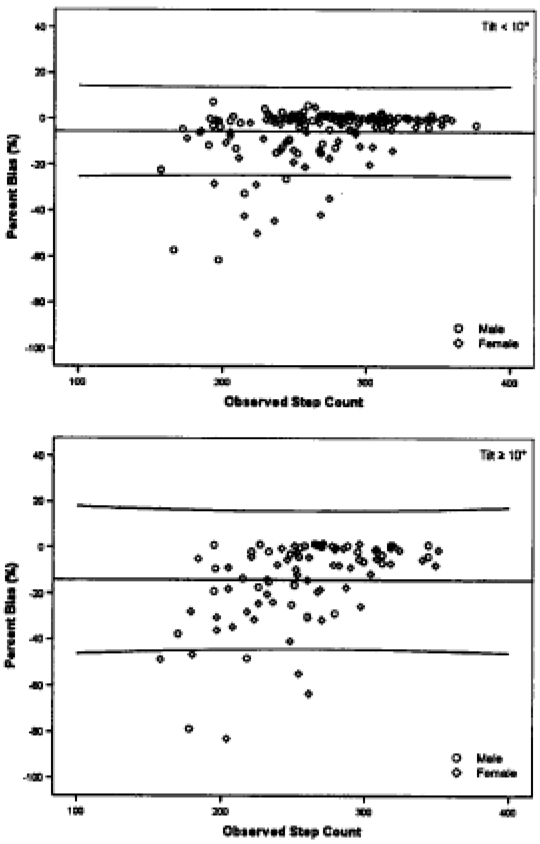

Figure 3. Modified Bland-Altman plots showing percent bias of the SW-200 pedometer for children at walking speeds of 42-90 m•min⁻¹. Data for the two tilt angle groups (< 10° and ≥ 10°) are presented separately with mean percent bias (straight line) and 95% prediction interval (curved lines).

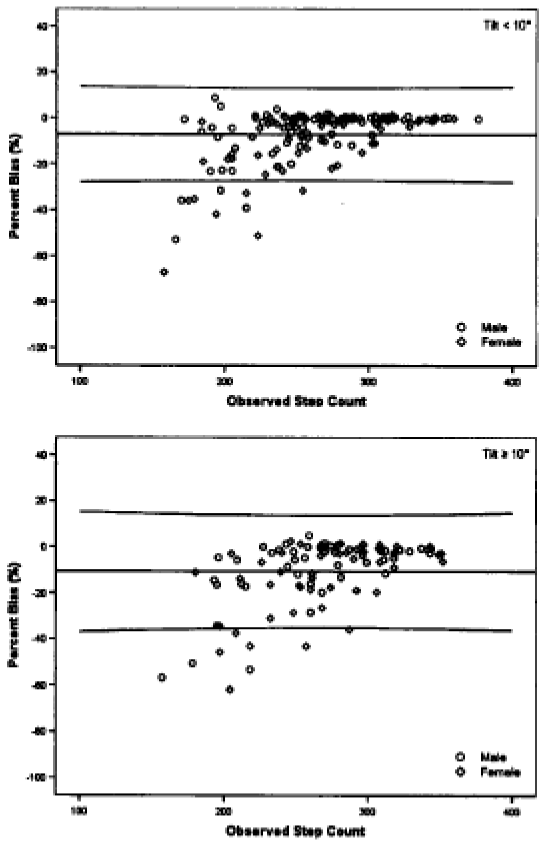

Figure 4. Modified Bland-Altman plots showing percent bias of the NL-2000 pedometer for children at walking speeds of 42–90 m•min⁻¹. Data for the two tilt angle groups (< 10° and ≥ 10°) are presented separately with mean percent bias (straight line) and 95% prediction interval (curved lines).

take long, controlled steps during slow/moderate walking may generate less vertical acceleration forces (and therefore more undetected steps) than those who have short, jolting gaits. Differences in walking style may also account for the smaller overall bias observed in boys when compared with girls.

A potential solution to the systematic undercounting of SW-200 and NL-2000 pedometers at slow speeds is to lower the force threshold for step detection. However, the subsequent increase in sensitivity would be accompanied by a reduction in specificity under free-living conditions, such that a greater number of nonstep movements (e.g., jolting during car travel) would be incorrectly interpreted as steps (Le Masurier et al., 2004). It is therefore relevant to consider whether reducing undercounting at slow speeds merits the increase in error from artificial sources. It could be argued that slower steps require less energy expenditure and are therefore less important to detect than steps achieved at faster speeds. On the other hand, given that the relationships between various walking speeds and health benefits may change with age and body size, it may be presumptive to label a specific walking speed as "unimportant." The first step is to investigate the tradeoff between sensitivity and specificity that arises from altering the step detection threshold of pedometers in free-living conditions.

As with pedometer accuracy, the precision of step count estimates was also lower at a slow walking speed. The wide 95% limits of agreement observed at a speed of 42 $m \cdot min^{-1}$ imply that only inter-individual differences greater than 37.6% and 31.9% could be confidently identified by SW-200 and NL-2000 pedometers, respectively. For a child averaging 15,000 steps per day, the limits of agreement correspond to a detectable difference of ± 5,640 (SW-200) and ± 4,785 (NL-2000) steps. These limits narrow to ± 2,385 and ± 1,770 steps for moderate walking and to ± 990 and ± 555 steps for fast walking. Given that the smallest meaningful difference in activity is generally considered to be 1,000 steps per day (Tudor-Locke et al., 2004), it follows that both pedometer models are effective for detecting change during fast walking only. However, it should be noted that a larger test sample would almost certainly result in smaller limits of agreement for all speeds. The loss of precision is a more important statistic for population research, as it indicates the theoretical increase in sample size required to offset the random error associated with pedometers. Our results suggest that the sample size must be increased by 109% to compensate for the use of SW-200 pedometers (as opposed to a hand counter) during slow walking (67% for NL-2000), but only by 7% when measuring fast walking (3% for NL-2000).

The present results clearly support the view that pedometers are less effective for measuring children's steps at slow compared with fast walking speeds. However, the practical significance of this finding is uncertain because the relationship between slow walking and health benefits in children is not well understood. The importance of pedometer inaccuracy at slow speeds also depends on the frequency of slow walking in children. Beets et al. (2005) reported that pedometer performance during self-paced walking was similar to that observed during treadmill walking at a brisk speed (80 $m \cdot min^{-1}$). Indeed, all 20 children tested moved at speeds above 65 $m \cdot min^{-1}$ when asked to walk normally around an athletic track, suggesting that speed-related pedometer error may not be an issue during self-paced walking in children. Nonetheless, the speeds at which children move during other activities (e.g., free play or sports) are not known. The recent development of portable global positioning units that are able to record spatial location at high sampling frequencies may provide researchers with a means to collect this information.

The accuracy of pedometers in different age groups was also examined in this study. Because young children tend to exhibit a less mature gait (Jeng et al., 1997) and generate lower GRF (Takegami, 1992) than older children, we hypothesized that the number of undetected steps would be greater in participants from Years 1–2 than those from Years 5–6. On the contrary, the percent error for both pedometers was highest in older children. It appears likely from our observations that the limited ability of younger children to modulate walking frequency on a treadmill (Jeng et al., 1997) induced a jolting gait that generated abnormally large GRF. This would explain the age-specific trends observed in the present study, but it also raises concerns over the use of treadmills to simulate typical walking in young children. The likelihood of uncharacteristic walking patterns could be reduced by assessing overground walking in young children; however, it is difficult to regulate walking speed when using this method. In any case, our results suggest that age-related variation in pedometer performance is only relevant during slow walking speeds.

In view of recent moves to prescribe step count targets for children based on overweight status (Duncan, Schofield, & Duncan, 2007; Tudor-Locke et al., 2004), it is vital for pedometers to be able to accurately measure physical activity in children with excess adiposity. We chose to include both overweight and non-overweight children in order to examine the association between body composition and pedometer validity across a wide range of body sizes. The results confirm that tilt angle is a more important contributor to pedometer error than adiposity, which is consistent with previous findings in obese adults (Crouter et al., 2005). In fact, none of the three body-composition measures that were tested (BMI, WC, and %BF) showed significant associations with percent bias (when adjusted for all other independent variables). In contrast, an absolute tilt angle ≥ 10° corresponded to a 2.6- and 1.5-fold increase in step count underestimation for the SW 200 and NL 2000 (respectively) when all three speeds were combined. Further analyses revealed that the effects of tilt angle on mean percent bias were relatively constant across sex and age groups. The precision of step count estimates also decreased markedly in individuals with large pedometer tilt, irrespective of sex or age group, particularly for the SW-200 model.

These findings suggest that variables other than body composition are responsible for the degree of pedometer tilt in children. In our study, a large tilt angle was observed in over a third of the participants but was unrelated to BMI, WC, or %BF. We propose that the style of waistband on the clothing worn by the child is the most important determinant of pedometer tilt. It was apparent from our observations that attaching a pedometer to loose waistbands with limited elasticity often resulted in the pedometer tilting away from the vertical plane. Thus, children with unsuitable clothing may experience a reduction in pedometer accuracy regardless of their body size. Although they did not measure tilt angle, Ramírez-Marrero et al. (2002) noticed that bias at slow walking speeds decreased after moving the pedometer from the midline of the thigh (as per the manufacturer's instructions) to a pouch secured by a belt around the waist. This suggests that fastening the pedometer to a belt system rather than relying on the existing clip on the back of the pedometer may improve stability and minimize undercounting of steps.

To our knowledge, the present study is the first to validate the piezoelectric NL-2000 pedometer in a pediatric sample. The NL-2000 showed similar accuracy and better precision than the spring-levered SW-200 pedometer, with noticeably superior performance at large tilt angles. The latter disparity between models appears even greater in obese adults; Crouter et al. (2005) reported a significant association between tilt angle and absolute error for the SW 200 but not for the NL 2000. A possible explanation is that the GRF produced by obese adults when walking is large enough to overcome the dampening effects of excessive tilt in piezoelectric pedometers. Our findings suggest that while the walking forces generated by children are not sufficient to offset all tilt-related error in NL 2000 pedometers, the accuracy and precision of this pedometer is less compromised by a large tilt angle than is the spring-levered SW 200. The MDM capabilities of the NL-2000 are another prospective benefit for researchers. However, the greater cost of the NL 2000 ($60) compared with the SW-200 ($17) may preclude its use in large-scale studies. The purchase of multiple belt systems to reduce tilt-related error may be another financial issue to consider.

In summary, SW-200 and NL-2000 pedometers show acceptable accuracy and precision for recording step counts in children at moderate and fast walking speeds, but not at slow walking speeds. Pedometer bias was not affected by body composition, but was positively associated with absolute tilt angle for both pedometers. Our results also suggest that piezoelectric pedometers provide a more precise estimation of children's step counts than spring-levered models. In order to minimize tilt angle and reduce measurement error, we recommend the use of a firm elastic belt system when using pedometers to measure steps in children.

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Effects of Weather on Pedometer-Determined Physical Activity in Children

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ABSTRACT

DUNCAN, J. S., W. G. HOPKINS, G. SCHOFIELD, and E. K. DUNCAN. Effects of Weather on Pedometer-Determined Physical Activity in Children. *Med. Sci. Sports Exerc.*, Vol. 40, No. 8, pp. 1432–1438, 2008. The effects of weather conditions on children's physical activity have not been well described. **Purpose:** To evaluate the effects of meteorological variables on the number of pedometer steps accumulated by children. **Methods:** Between August and December 2004 (winter to summer), 1115 Auckland children (536 boys, 579 girls; aged 5–12 yr) from 27 socioeconomically and ethnically diverse schools wore sealed multiday memory pedometers for five consecutive days (three weekdays and two weekend days). Values of daily (7 a.m. to 7 p.m.) mean ambient temperature, mean wind speed, precipitation, and duration of bright sunshine were obtained from local meteorological stations. The independent effects of each of these variables on step counts were estimated using composite mixed linear models. Effects were standardized for interpretation of magnitudes. **Results:** Weekday and weekend-day step counts for boys were 16,100 ± 5000 and 12,900 ± 5900 (mean ± SD), whereas those for girls were 14,200 ± 4200 and 11,300 ± 4800. A 10°C rise in mean ambient temperature was associated with a small increase in weekday steps [1700; 90% confidence intervals (CI) ±1300] and a moderate increase in weekend-day steps (3400; 90% CI ±1500) for boys, whereas for girls the effects were small (2300; 90% CI ±1000) and unclear (−300; 90% CI ±1200), respectively. There were substantial decreases in weekday and weekend-day steps during moderate rainfall (1.1–4.9 mm) for both sexes. Most effects of day length, wind speed, and hours of bright sunshine on step counts were trivial or unclear. **Conclusions:** Ambient temperature and rainfall have substantial effects on children's daily step counts and should therefore be considered when comparing physical activity across different locations or periods. Strategies to increase activity on cold or rainy days may also be appropriate. **Key Words:** PEDIATRIC, STEP COUNT, BEHAVIOR, OBJECTIVE MEASUREMENT, TEMPERATURE, RAINFALL

Regular physical activity during childhood can improve bone health, blood lipid profile, and self-efficacy and can reduce the risk of obesity and hypertension (5). Consequently, increasing physical activity in young people is a key public health priority in many countries. Given the increasing support for initiatives that encourage children to adopt or maintain an active lifestyle, it is important to understand the determinants of physical activity in this age group. Previous research has identified numerous demographic, sociocultural, psychologic, cognitive, and behavioral factors related to physical activity in young people (21,28). However, there is limited information describing the interactions between children's activity patterns and physical environment.

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An environmental factor often overlooked in previous research concerns the effect of inclement weather on physical activity. Periods of heavy rainfall, strong wind, and low temperatures are not conducive to outdoor play and may result in a reduction in overall activity levels. This prospect has important implications for the surveillance of children's physical activity because weather conditions may confound comparisons between samples from distinct geographical locations. The evaluation of physical activity levels pre- and postintervention may also be confounded by meteorological variation. Furthermore, an appreciation of the environmental barriers to physical activity in children is requisite for developing strategies that promote physical activity in all weather conditions.

Although numerous surveys have noted that physical activity participation in temperate climates tends to be highest in summer and lowest in winter (2,4,7,10,15–17,26,27,29), few have elucidated the specific weather-related variables responsible for seasonal differences. Togo et al. (23) reported that activity in Japanese older adults increased with mean ambient temperature between −2 and 17°C and decreased between 17 and 29°C, with an exponential decrease in activity as precipitation increased. Similarly, Chan et al. (8) described a 2.9% increase in physical activity for every 10°C rise in mean ambient temperature among Canadian adults and a 5.2–8.3% decrease during periods of rainfall. Other meteorological factors negatively associated with activity included maximum wind speed, total snowfall, and amount of snow on the ground. Conversely, McGinn et al. (18) found no associations between physical activity in American adults and a daily weather score derived from heat index, wind chill, standardized pressure, and precipitation.

The only study to consider the effects of multiple weather-related variables on children's physical activity reported inconsistencies between sexes. In their sample of UK children aged 11–12 yr, Brodersen et al. (6) showed that rainfall reduced activity levels in girls and that sedentary behavior was more common at low temperatures than at high temperatures in boys. However, activity data were collected using a self-report questionnaire that assessed the frequency of vigorous exercise only. Given that vigorous exercise typically represents only a small proportion of overall activity (19,25), the impact of weather on habitual physical activity in children remains uncertain. Also unresolved is the potential difference between weather effects on weekdays and weekend days. For example, possibly weather conditions have greater effect on weekend activity than on the structured physical activity that occurs at school. The purpose of the present research, therefore, was to characterize the effects of a series of meteorological variables (day length, rainfall, temperature, wind speed, and the duration of bright sunshine) on the number of pedometer steps accumulated by children on weekdays and weekend days. In addition, associations between weather variables and activity were compared across a range of sex, age, and socioeconomic groups.

METHODS

This study represents a secondary analysis of an existing data set. The recruitment and physical activity procedures have been described in detail elsewhere (11), with only a brief overview given here. However, the collection and treatment of meteorological data and the statistical analyses are novel aspects of the study and are explained in full.

Participants. A total of 2000 children (1000 boys and 1000 girls) aged 5–12 yr were randomly selected from 27 elementary schools (grades 1–6) in Auckland, New Zealand. Participating schools were purposively sampled to replicate the overall geographic and socioeconomic distribution of elementary schools in the Auckland region. Consent was obtained for 1251 of 2000 children selected (62.6%), and 1115 children (536 boys and 579 girls) were included in the final data set. Participants were evenly spread across grade levels (grades 1–2 = 30.4%; grades 3–4 = 34.1%; grades 5–6 = 35.5%). The ethnicity of this sample was as follows: 549 Europeans (49.2%), 334 Polynesians (30.0%), 184 Asians (16.5%), and 48 from other ethnic groups (4.3%). Socioeconomic status (SES) was estimated using the Ministry of Education decile classification system for New Zealand primary schools. This system determines the extent to which schools draw their students from low SES communities, which are identified from five national census factors: income, occupation, household crowding, educational qualifications, and income support. Participants from schools with a decile rating of 1–3 were categorized into the "Low" SES group (34.6%), whereas those from schools rated 4–7 and 8–10 were considered "Middle" (28.9%) and "High" (36.5%), respectively. Ethical approval for this study was obtained from the Auckland University of Technology Ethics Committee. Written informed consent was provided by each participant and his/her legal guardian.

Physical activity. Physical activity was measured using sealed multiday memory (MDM) pedometers (Model NL-2000; New Lifestyles, Inc, Lee's Summit, MO) over three weekdays and two weekend days. Previous pedometry research has shown that the NL-2000 offers similar accuracy and better precision for measuring steps in children than the widely used Yamax SW-200 pedometer (12). The collection of 5 d of data required the weighting of overall mean step count values by five weekdays to two weekend days to replicate a typical 7-d week. However, previous research indicates that 5 d of monitoring is sufficient to obtain reliable estimates of physical activity in children (24). Before use, all pedometers were checked for faults using five repetitions of the 100-step walking test described by Vincent and Sidman (30). Instrumental error did not exceed 3% in any of the pedometers. Before receiving their sealed MDM pedometers, children were given an explanation of the pedometer's function and a demonstration by a researcher. Participants were asked to attach the pedometer to their waistline all day except when swimming or sleeping. To assess participant compliance outside the school environment, parents/caregivers completed a questionnaire the night before the pedometers were collected in which they were asked to note how many hours their child was not wearing the pedometer. Noncompliance during school hours was considered negligible because of active teacher assistance. Data were excluded if participants removed the pedometer for more than 1 h on a given day. Daily step counts of less than 1000 or more than 30,000 were regarded as outliers and were removed (20).

Weather. Testing took place in Auckland, New Zealand, during the winter, spring, and summer months between August and December 2004 (exclusive of any school holidays). The mean ambient temperatures in Auckland range from 17–23°C in summer to 8–13°C in winter, reflecting its location in a warm-temperate zone (36°51′S, 174°47′E). Access to data from three separate weather stations in the Auckland region was provided by the National Meteorological Service of New Zealand. The weather data ascribed to each participant were obtained from the station closest to their school (mean distance = 11.4 ± 5.9 km; range = 2.6–21.8 km). Total rainfall (mm), mean ambient temperature (°C), mean wind speed (km·h^{-1}), and the duration of bright sunshine (no cloud cover) were recorded for the hours between 7 a.m. and 7 p.m. on each day of the monitoring period. This 12-h epoch was chosen because the weather conditions before 7 a.m. or after 7 p.m. are unlikely to have an effect on the children's activity choices (2). Sunrise and sunset times for every seventh day of the study period were provided by the National Observatory of New Zealand. A sinusoidal curve was fitted to the data ($r^2 = 1.00$) to enable the day length (hours between sunrise and sunset) to be estimated for each day of testing.

Statistical analyses. Data of this nature require mixed modeling to specify not only the usual linear (fixed effects) model but also other important sources of variation (random effects) such as school variance and between-subject variance. Although this level of complexity imposes high computational demands, it allows for greater accuracy in model fitting than ordinary linear regression (9). In the present study, the effects of the five weather variables on step counts were assessed using the appropriate mixed model (Proc Mixed) in the Statistical Analysis System (Version 9.1; SAS Institute, Cary, NC). The fixed effects were sex × day type, sex × grade, sex × SES, and the interactions of each weather variable (day length, rainfall, temperature, wind speed, and duration of bright sunshine) with sex and day type. Although initial univariate analyses were performed (each weather variable assessed separately), only minor differences to the full model were observed, and consequently the results are not presented here. Furthermore, interactions among weather variables were not included because of excessive data processing requirements. Owing to its skewed distribution, rainfall was coded as an ordinal variable representing no rainfall (0 mm), light rainfall (0.1–1.0 mm), moderate rainfall (1.1–4.9 mm), and heavy rainfall (>5 mm). All other weather variables were analyzed as continuous linear predictors. The random effects were school variance and between-subject variance (grouped by sex). The aforementioned procedure was repeated twice: once with grade (1–2, 3–4, and 5–6) and once with SES (high, middle, and low) replacing day type in all three-way interactions with sex and weather variables. Inspection of residual versus predicted plots showed greater nonuniformity in scatter after log transformation of step counts when compared with nontransformed data; raw step counts were therefore used in all analyses.

The effects of unit increases in the five weather variables on step counts (adjusted for all fixed effects in the mixed models) were determined separately across all sex, day type, grade, and SES groups. To understand the relevance of these results, the standardized effects of meaningful differences in each weather variable were determined. The SD values used in the standardization process were calculated for boys and girls separately by combining the between-school SD, the pure between-subject SD, and the weekday and weekend within-subject SD values (weighted by five weekdays to two weekend days) obtained from the mixed model. The effects of a 10°C increase in mean ambient temperature and a 5-h increase in day length were assessed, representing the approximate differences between summer and winter in Auckland. The effects of increasing rainfall by two categories (no rain to moderate rain, or light rain to heavy rain) and wind by 25 km·h^{-1} were also investigated, as was the effect of a 6-h increase in the duration of bright sunshine (half of the 12-h epoch between 7 a.m. and 7 p.m.).

Magnitudes of the standardized differences in means were interpreted using thresholds of 0.2, 0.6, and 1.2 for small, moderate, and large, respectively. These values were developed to correspond with Cohen's thresholds for small, moderate and large correlation coefficients (r = 0.1, 0.3, and 0.5, respectively) (3). A trivial effect was noted when the effect size was less than 0.2. Inferences about the effects of weather on population step counts were made by expressing uncertainty as 90% confidence intervals (CI) (22). Thus, the chances that the true value lies above the upper limit or below the lower limit are both 5%; interpreted previously "very unlikely" (3). An effect was deemed unclear if its CI extended beyond the thresholds defining both substantial positive and negative effects. Otherwise, the magnitude of the effect was reported as the magnitude of the observed value.

RESULTS

Figure 1 shows the weather variables recorded during the study period (August to December 2004) for the Auckland region. Day length (mean ± SD, 12.9 ± 1.5 h) and mean temperature (15.2 ± 2.7°C) increased from the last month of winter (August) to the first month of summer (December), but total rainfall (1.3 ± 3.2 mm), mean wind speed (23.7 ± 8.9 km·h^{-1}), and duration of bright sunshine (2.6 ± 3.3 h) did not display any obvious seasonal variation.

Table 1 gives the mean weekday and weekend-day steps for the sample (after adjustment for grade, SES, and each of the five weather variables) and the adjusted mean step counts (weighted by five weekdays to two weekend days) among grade and SES groups. Boys consistently accumulated more steps than girls across all demographic groups and day types. Compared with weekdays, step counts on weekend days were considerably lower for boys and girls. Step counts tended to decrease in girls (but not in boys) with increasing school grade. There were no apparent trends in step counts across SES groups for either sex. The standard deviations for the mixed model are also given in Table 1: the between-school variation contributed the least to the overall observed variation, whereas the day-to-day variation in a child's step count was approximately double the observed variation between children.

Overall, there was a positive effect of mean temperature and a negative effect of rainfall on daily step counts. Effects of day length, mean wind, and hours of bright sunshine

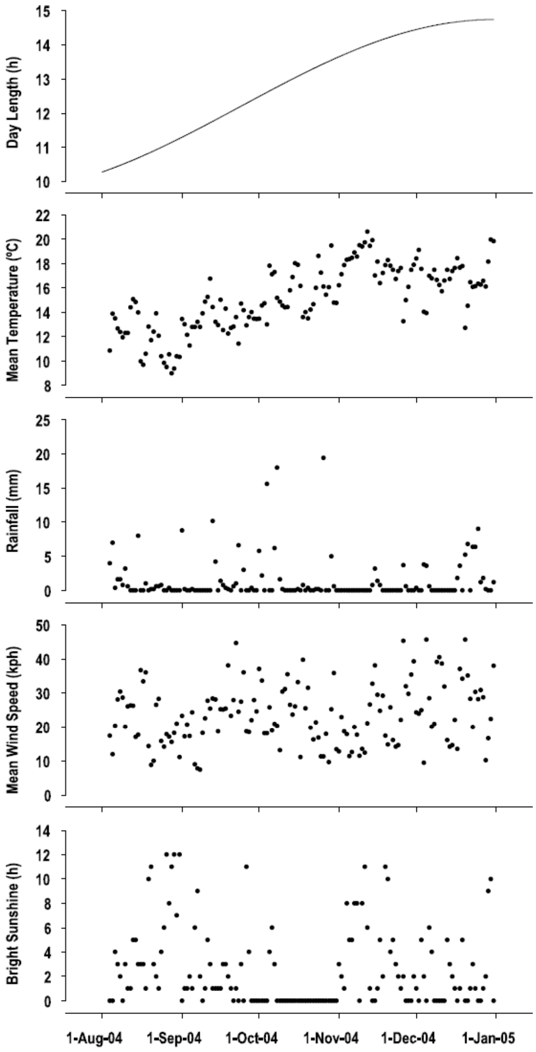

FIGURE 1—Variation in day length, mean ambient temperature, total rainfall, mean wind speed, and the duration of bright sunshine between August and December 2004 in Auckland, New Zealand.

were more variable. Tables 2 and 3 show the mean effects and their magnitudes for selected changes to each of the five weather variables. In boys, a 10°C increase in mean temperature had a larger effect on weekend-day step counts (moderate) than on weekday step counts (small). By contrast, the equivalent increase in mean temperature had a trivial effect on weekend-day step counts and a small effect on weekday step counts in girls. Corresponding effect magnitudes across grade and SES groups were also variable, ranging from trivial to moderate. The negative effect of moderate rainfall on step counts was similar across day types and grade groups for both sexes. However, there was a trend for the effect of rainfall to increase with SES. Effects of the selected changes to day length, wind speed, and hours of bright sunshine on step counts were largely trivial or unclear.

DISCUSSION

It is generally accepted that inclement weather can discourage physical activity participation in young people (2,4). Although the weather itself cannot be controlled, an understanding of the conditions that present the greatest barriers to activity in children is useful for informing the delivery of alternative options to outdoor play. This study represents the first investigation of the associations between meteorological factors and habitual physical activity levels in a pediatric sample. Our results indicate that a decrease in mean ambient temperature and an increase in total rainfall can have a negative impact on step counts, regardless of day length, mean wind speed, or duration of bright sunshine. Thus, studies comparing physical activity levels across different locations or periods may need to account for the confounding effects of temperature or rainfall variation.

The magnitude of the effect of temperature on step counts was dependent on sex, day type, grade level, and SES. For example, temperature had moderate effect on weekend activity in boys but had an unclear effect on weekend activity in girls. Although the reasons for this sex-related variation are uncertain, possibly outdoor activities influenced by ambient temperature are more popular in boys than in girls. Expressed as percent effects on daily steps (for comparison with other studies), the seasonal variation in temperature from winter to summer months corresponded to 11% more weekday steps and 26% more weekend steps for boys, and 16% more weekday steps for girls. These percentage increases are considerably greater than the 2.9% increase in daily steps observed for a 10°C rise in temperature in Canadian adults (8) but similar to the 14% increase in daily steps between 0 and 10°C in Japanese adults (23). As neither study quantified the difference

TABLE 1. Steps per day adjusted to mean values of day length, total rainfall, mean ambient temperature, mean wind speed, duration of bright sunshine, grade group, and SES group.

	Boys (*n* = 536)	Girls (*n* = 579)
Mean values		
Weekday	16,100	14,200
Weekend day	12,900	11,300
Grades 1–2[a]	15,500	14,100
Grades 3–4[a]	15,100	13,500
Grades 5–6[a]	15,000	12,500
Low SES[a]	15,100	13,800
Middle SES[a]	15,000	13,200
High SES[a]	15,300	13,200
SD		
Between-school	690	690
Between-subject	2500	2100
Within-subject (weekdays)	4300	3600
Within-subject (weekend)	5300	4300
Overall (weekday)[b]	5000	4200
Overall (weekend day)[b]	5900	4800

[a] Weighted mean step count (five weekdays and two weekend days).
[b] Observed typical variation in step count between children on a given day.

TABLE 2. Differences in steps per day (90% CI) and corresponding qualitative effect magnitudes[a] for selected weather variable increases in 536 boys aged 5–12 yr.

	Mean Temperature (+10°C)	Rainfall (+2 Categories)	Day Length (+5 h)	Wind Speed (+25 km·h^{-1})	Bright Sunshine (+6 h)
Day type					
Weekday	1700 (±1300) Small (+)	−1700 (±460) Small (−)	−900 (±1700) Trivial	500 (±750) Trivial	0 (±480) Trivial
Weekend	3400 (±1500) Moderate (+)	−1700 (±880) Small (−)	−200 (±1900) Unclear	0 (±1000) Trivial	360 (±780) Trivial
Grade[b]					
1–2	1800 (±1800) Small (+)	−1300 (±700) Small (−)	−150 (±2300) Unclear	500 (±1000) Trivial	−180 (±660) Trivial
3–4	3000 (±1800) Small (+)	−2100 (±680) Small (−)	−1300 (±2100) Small (−)	−250 (±1000) Trivial	−120 (±720) Trivial
5–6	1400 (±1700) Small (+)	−2000 (±680) Small (−)	−700 (±2200) Unclear	750 (±1000) Trivial	360 (±660) Trivial
SES[b]					
Low	4400 (±2300) Moderate (+)	−2400 (±620) Small (−)	−1400 (±2700) Unclear	0 (±1000) Trivial	60 (±900) Trivial
Middle	−1000 (±1800) Trivial	−1900 (±700) Small (−)	−250 (±2500) Unclear	250 (±1000) Trivial	−60 (±900) Trivial
High	2600 (±1700) Small (+)	−2600 (±880) Small (−)	−600 (±3100) Unclear	1000 (±1000) Trivial	−60 (±540) Trivial

Three separate mixed models were used for day type, grade, and SES, with each model adjusted for all five weather variables.
[a] On the basis of standardized differences in means of <0.20 (trivial), 0.20–0.59 (small), and 0.60–1.19 (moderate). An effect was deemed unclear if the 90% CI extended beyond −0.2 and 0.2.
[b] Weighted mean step count (5 weekdays and 2 weekend days).

between weekday and weekend step counts, it is unclear whether the effect of mean ambient temperature on adult activity is dependent on day type. In the present study, differences in the association between temperature and step counts were also observed across SES groups, with the middle SES group in boys and the high SES group in girls showing trivial and unclear temperature effects, respectively. The impact of weather on activity is clearly a complex issue that is contingent on interactions between several demographic variables.

Although our results indicate that temperature changes between winter and summer months can have meaningful effects on children's daily activity in a temperate climate, it is also important to consider the potential effects of day-to-day variation in temperature. The practical relevance of temperature effects can be evaluated by interpreting the standardized effect size relative to the maximum temperature variation in an average week (3.3°C in the present study). Although the mean effect of a 10°C (seasonal) increase in mean ambient temperature on weekday steps was small for both boys and girls, the mean effect of a 3.3°C increase would be trivial. Small effects of day-to-day variation in temperature were only observed for weekend steps in all boys and for overall weighted step counts in low-SES boys. These findings suggest that the typical temperature variation within a given week in the Auckland region is only sufficient to influence activity choices in certain subpopulations of children. However, individuals exposed to climates with greater day-to-day variation in mean temperature are more likely to exhibit weather-related activity patterns during the week. The inclusion of temperature as an independent variable should therefore be considered in studies that monitor children's physical activity during multiple days.

TABLE 3. Differences in steps per day (90% CI) and corresponding qualitative effect magnitudes[a] for selected weather variable increases in 579 girls aged 5–12 yr.

	Mean Temperature (+10°C)	Rainfall (+2 Categories)	Day Length (+5 h)	Wind Speed (+25 km·h^{-1})	Bright Sunshine (+6 h)
Day type					
Weekday	2300 (±1000) Small (+)	−1180 (±360) Small (−)	−750 (±1450) Trivial	0 (±750) Trivial	420 (±360) Trivial
Weekend	−300 (±1200) Unclear	−1840 (±680) Small (−)	900 (±1600) Small (+)	0 (±750) Trivial	420 (±600) Trivial
Grade[b]					
1–2	700 (±1600) Unclear	−820 (±580) Trivial	550 (±2050) Unclear	0 (±1000) Unclear	900 (±600) Small (+)
3–4	1400 (±1400) Small (+)	−1920 (±560) Small (−)	500 (±1800) Unclear	0 (±750) Trivial	120 (±540) Trivial
5–6	1500 (±1300) Small (+)	−1120 (±5000) Small (−)	−850 (±1750) Unclear	−250 (±750) Trivial	360 (±540) Trivial
SES[b]					
Low	1400 (±1700) Small (+)	−860 (±460) Small (−)	500 (±2250) Unclear	−750 (±750) Trivial	1440 (±720) Small (+)
Middle	1400 (±1500) Small (+)	−1460 (±580) Small (−)	−1100 (±2300) Unclear	−250 (±750) Trivial	60 (±720) Trivial
High	200 (±1400) Unclear	−2000 (±720) Small (−)	1900 (±2750) Unclear	1500 (±1000) Small (+)	240 (±480) Trivial

Three separate mixed models were used for day type, grade, and SES, with each model adjusted for all five weather variables.
[a] On the basis of standardized differences in means of <0.20 (trivial), 0.20–0.59 (small), and 0.60–1.19 (moderate). An effect was deemed unclear if the 90% CI extended beyond −0.2 and 0.2.
[b] Weighted mean step count (five weekdays and two weekend days).

It is interesting to note that the positive relationships between ambient temperature and step counts were independent of day length, whereas the effects of day length on step counts after adjustment for mean ambient temperature were largely unclear. It follows that the peak in physical activity participation commonly observed during the summer months (2,7,10,16,26,27,29) may reflect ambient temperatures that encourage outdoor pursuits rather than the number of daylight hours available for physical activity. Previous research in adults has reached similar conclusions: Chan et al. (8) reported that mean ambient temperature had a significant effect on activity independent of the month of the year, whereas Togo et al. (23) found that temperature had a stronger association with activity than day length. Thus, developing and promoting physical activity opportunities during cold periods may be a worthwhile strategy for people of all ages.

The effects of precipitation on daily activity showed greater consistency than the effects of mean ambient temperature. In accordance with previous research in adults (8,23), moderate rainfall had a small negative effect on weekday and weekend activity for both sexes. These effects translate to 11% and 8% decreases in steps per day for boys and girls, respectively, on weekdays and to 14% and 16% decreases in steps per day for boys and girls, respectively, on weekends. Although effects were similar across grade groups, the impact of rainfall on daily activity increased with SES. Possibly children from a low socioeconomic background participate in fewer organized sports (which are subject to rain cancellations) and/or place greater reliance on active transport than high SES children. Different ethnic or cultural norms linked with SES may also contribute to the association between precipitation and physical activity. In any case, offering alternative activities to counteract the reduction in children's activity during moderate to heavy rainfall is clearly a priority for lifestyle interventions. An understanding of how the distribution of rainfall throughout the day affects activity choices would be beneficial in this regard.

Our analyses for the effects of wind speed between the hours of 7 a.m. and 7 p.m. indicate that the occurrence of windy conditions does not influence physical activity behavior in children living in Auckland, New Zealand. In contrast, Canadian adults showed a 2%–5% decrease in activity with maximum wind speeds greater than 20 $km \cdot h^{-1}$ (8). Given that the peak wind speed in the Canadian study was estimated over a 24-h period, it is likely that the decline in activity associated with high winds would be even greater if the wind conditions had been determined for daylight hours only. Although similar research in Japanese adults found no correlation between mean wind speed and activity (23), the wind speeds assessed in the latter study were relatively low (<20 $km \cdot h^{-1}$). Nevertheless, we observed predominantly trivial effects even at a mean wind speed of 25 $km \cdot h^{-1}$. The differences between studies may reflect a tendency for children to be less discouraged by moderate to high winds than adults. Alternatively, inherent differences in the impact of windy conditions on physical activity may exist between countries due to population-specific social norms. Comparing the effects of wind on activity in children and adults from the same population would help to clarify this issue. Another meteorological factor that may require further study is the duration of bright sunshine: this variable also had little impact on activity in the present sample but a significant effect in previous research in adults (23).

Mean ambient temperature and rainfall seem to be the most important weather-related determinants of children's physical activity in temperate climates, but devising appealing opportunities for children to be physically active on cold and/or rainy days could be challenging. Schools have a significant role to play by offering indoor activity when children are not permitted to play outside (e.g., during wet lunchtimes). Out of school, the availability of community facilities for indoor recreational activity (e.g., gymnasiums, swimming pools) is an important factor. Another potential strategy is to ensure that parents are able to provide children with active options within the home environment. Promoting the use of suitable clothing to allow walking in all weather conditions may be worthwhile in this regard. Future research is required to determine the most effective approaches for counteracting the detrimental effect of cold temperatures and rainfall on children's activity.

A potential limitation of this study is that weather data were collected at fixed stations 3–15 km away from participating schools. Furthermore, the distances between the weather stations and participants' home locations were not collected. It is therefore possible that localized weather conditions experienced by some children may not have been evident in our data. However, exploratory comparisons of the meteorological variables collected each station (data not shown) suggested that the differences in weather patterns between regions were negligible. It should also be noted that the present findings are characteristic of children living in Auckland, New Zealand. As such, the effects of elements common in nontemperate climates (e.g., snowfall, extreme temperatures) on physical activity in children require further investigation. Identifying significant interactions between meteorological variables is another area for future research. Although current data processing limitations restrict the number of interactions able to be tested, a combination of one or more weather factors may have resulted in synergistic effects on physical activity.

Although pedometers provide a measure of total daily physical activity, they do not give an indication of the specific weather-related changes in activity patterns that may occur within a given day. The use of measurement techniques that are able to record the frequency and intensity of activity (e.g., accelerometers, heart rate monitors) would provide insight into children's short-term responses to variable weather conditions. It should also be noted that seasonal differences in activities not captured by pedometers (e.g., cycling, swimming) would not be observable. In fact, possibly the differences in activity between day types may reflect a greater frequency of undetected activities on weekend days when compared with weekdays. However, given that the majority of children's activity is ambulatory in nature (1) and that pedometers correlate well with other objective measures (13,14), the exclusion of nonambulatory activities is unlikely to confound the results.

In summary, this study provides the first data describing the associations between weather conditions and daily physical activity levels in children. Our results indicate that moderate rainfall and a reduction in mean ambient temperature can have small to moderate negative effects on children's activity in a temperate climate. Furthermore, interactions among weather conditions, day type, and demographic factors suggest that the impact of weather on children's physical activity during weekdays and weekends is not consistent for all population subgroups. Nevertheless, the development of appropriate activity options for cold and/or rainy days is likely to have beneficial effects on children's physical activity.

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Pedometer-Determined Physical Activity and Body Composition in New Zealand Children

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ABSTRACT

DUNCAN, J. S., G. SCHOFIELD, and E. K. DUNCAN. Pedometer-Determined Physical Activity and Body Composition in New Zealand Children. *Med. Sci. Sports Exerc.*, Vol. 38, No. 8, pp. 1402–1409, 2006. **Purpose:** The objectives of this study were to examine current levels of pedometer-determined physical activity in a multiethnic sample of New Zealand children and to investigate associations among weekday and weekend step counts, body mass index (BMI), waist circumference (WC), and percentage body fat (%BF). **Methods:** A total of 1115 children (536 boys, 579 girls) aged 5–12 yr wore sealed multiday memory pedometers for three weekdays and two weekend days. The ethnic composition of the sample was 49.2% European, 30.0% Polynesian, and 16.5% Asian, with 4.3% from other ethnicities. BMI was determined from height and weight, and %BF was measured using hand-to-foot bioelectrical impedance analysis. Participants were classified as normal weight, overweight, or obese using international BMI cutoff points (4), and into normal or central fat distribution groups using national WC standards (28). The 90th percentile of %BF for each age and sex subgroup was used to identify normal and high body fatness. **Results:** Mean step counts for this sample were 16,133 ± 3,864 (boys) and 14,124 ± 3,286 (girls) on weekdays, and 12,702 ± 5,048 (boys) and 11,158 ± 4,309 (girls) on weekends. Significant differences in step counts were observed between weekdays and weekends, boys and girls, and among age, ethnic, and socioeconomic groups. Analysis of variance revealed stronger associations between step counts and %BF category than between step counts and BMI or WC groups. **Conclusion:** This study provides evidence of a link between daily step counts and body fatness in children. Our results also suggest that the promotion of physical activity during the weekend is a key priority for young New Zealanders. **Key Words:** EPIDEMIOLOGY, BODY FAT, ETHNICITY, MULTIDAY MEMORY PEDOMETERS, STEP COUNTS

The escalation of obesity into a worldwide epidemic raises the prospect of serious health and economic consequences for many countries. Although the prevalence of obesity continues to increase in people of all ages (37), childhood obesity undoubtedly presents the greatest long-term concerns from a population health perspective. In the United States, obesity in children 6–11 yr of age (defined as a body mass index [BMI] at or above the 95th percentile of national growth charts) rose from 6.5% in 1976–1980, to 11.3% in 1988–1994, to 15.3% in 1999–2000 (19). These substantial increases in obesity are not exclusive to young Americans; similar patterns have been observed in other countries, including Australia (2), France (35), and the United Kingdom (3). Using international age- and sex-specific BMI cutoff points (4), a national survey conducted in 2002 found that 9.8% of New Zealand children were classified as obese (17). Furthermore, a recent study found that the risk of obesity in 2000 was 3.8 times greater than the risk in 1989 (33), suggesting that the prevalence of childhood obesity in New Zealand is following overseas trends.

Such findings have triggered an upsurge in the promotion of physical activity among young people as a long-term solution to the obesity epidemic. This has coincided with a widespread increase in the availability of step-counting pedometers for monitoring daily activity levels. For researchers, pedometers provide an objective, cost-effective assessment of physical activity that can be easily compared across different time periods, age groups, and locations (27). Pedometers are especially useful for studies of pediatric populations, where the inability of younger children to accurately recall their activity behavior can reduce the efficacy of questionnaires and interviews (23). Although pedometers are unable to detect physical activity intensity, duration, or frequency, there are clear benefits to recording a measurement unit that has direct applications to health promotion. Increasing the number of steps per day encourages the accumulation of physical activity in people of all ages and physical abilities and is less complicated than alternative recommendations based on physical activity intensity and duration. Pedometer-based interventions have already proved effective for increasing physical activity in adults (5,13) and adolescent girls (26).

Numerous descriptive studies have implemented pedometers to assess weekday physical activity in children (16,21,34), yet comparatively few have obtained separate

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data representing weekend days. The number of steps taken by children on the weekends is of particular interest, given the current evidence that young people are less active when outside the school environment (10,11). To discern step counts for individual days, conventional pedometers (e.g., the Yamax Digiwalker series) require researchers to visit participants at school each morning to record data from the previous day. Naturally, this procedure becomes more difficult during the weekend when children are at home. It is possible to obtain weekend data by relying on self-reported step counts; however, the prevalence of age-related recall bias or deliberate misrepresentation appears high in young people (29). Alternatively, the multiday memory (MDM) pedometer features an internal clock that automatically categorizes data according to the day of the week, enabling researchers to collect both weekday and weekend data while restricting participant contact to before and after the test period.

Although a daily step count target appears to be a promising approach for increasing population physical activity and thus lowering the risk of obesity, limited information describes the association between steps per day and body composition in children. In the only large-scale study of activity and body size in young people, Vincent et al. (34) found few significant relationships between weekday steps and BMI. The latter result is surprising given the growing body of longitudinal evidence supporting the role of physical activity in the prevention of childhood obesity (9,18). One possibility is that pedometers do not provide a suitably accurate estimate of physical activity to enable the detection of a significant association with body size. However, this is unlikely because previous research has established pedometers as a valid measure of activity in children (27). An alternative explanation is that BMI, as a weight-based index, is a simplistic indicator of adiposity. It is noteworthy that physical activity lowers the risk of obesity-related complications by reducing the accretion of body fat rather than decreasing body weight. The natural increases in height and weight that occur during growth may also complicate the relationship between BMI and physical activity. Indeed, several studies have observed stronger associations between activity and body fat than between activity and BMI (1,18). Even waist circumference (WC), a proxy measure of central fat accumulation, appears more closely related to activity levels in young people than BMI (12). We suggest that obtaining more direct measures of body fatness will increase the probability of detecting significant associations between pedometer steps and obesity in children.

It is clear that the association between steps per day and body composition in pediatric populations needs further clarification. Thus, the primary purpose of this study was to investigate pedometer steps in relation to BMI, WC, and percentage body fat (%BF) in a large sample of New Zealand children. A secondary objective was to compare differences in activity between weekdays and weekends, and among European, Polynesian, and Asian children.

METHODS

Participants. A total of 2000 children (1000 boys, 1000 girls) aged 5–12 yr were randomly selected from 27 primary (elementary) schools in Auckland, New Zealand. Participating schools were purposively sampled to replicate the overall geographic and socioeconomic distribution of primary schools in the Auckland region. Consent was obtained for 1251 of the 2000 children selected (68.3%), and 1229 children (603 boys, 626 girls) eventually took part in the study. Of this initial group, 29 participants (2.4%) either lost or damaged their pedometer during testing. A further 85 (6.9%) provided incomplete data and were excluded from analysis, resulting in a final sample size of 1115 (536 boys, 579 girls). The ethnic composition of this sample was 549 European children (49.2%), 334 Polynesian children (30.0%), 184 Asian children (16.5%), and 48 children from other ethnic groups (4.3%). The Polynesian ethnic group was composed of Pacific Island (56.0%) and Maori (44.0%) children, and the Asian ethnic group included Indian (38.0%), Chinese (22.3%), Korean (13.0%), Filipino (9.8%), Sri Lankan (4.3%), and other Asian (12.6%) children. Socioeconomic status (SES) was estimated using the Ministry of Education decile classification system for New Zealand primary schools. For the purposes of this study, participants from schools with a decile rating between 1 and 3 were categorized into the "low" SES group, whereas those from schools rated 4–7 or 8–10 were considered "middle" or "high," respectively. Although this proxy measure of SES may not accurately classify all individuals, it negated the potential parent or caregiver burden associated with a socioeconomic questionnaire. Ethical approval for this study was obtained from the Auckland University of Technology ethics committee. Written informed consent was provided by each participant and his or her legal guardian.

Physical activity. The New Lifestyles NL-2000 (Lee's Summit, MO) MDM pedometer was used to monitor daily physical activity. Previous research has shown that the NL-2000 offers a degree of accuracy comparable with the widely used Yamax Digiwalker series while providing the added benefits of a MDM function (25). Each NL-2000 pedometer was checked for defects before use in the study by observing the recorded step count after walking 100 paces. Instrumental error did not exceed 3% in any of the pedometers. Testing took place during the spring months between August and December. Each participant was given a short explanation about the study before receiving a demonstration about how to attach a presealed pedometer to the waistline. Participants were then asked to wear the pedometer all day for seven consecutive days (except when sleeping or swimming). On the seventh day of monitoring, researchers visited the participants to collect pedometers and record the number of steps taken on each of the testing days. Pedometers were not available to the participants on the morning of the first testing day or the evening of the last testing day, resulting in a maximum of 5 d of data (three weekdays and two weekend days). Previous research has suggested that 4–5 d of monitoring is sufficient to obtain a reliable (ICC > 0.80) estimate of physical activity in children (30).

To assess participant compliance outside of the school environment, parents or caregivers completed a questionnaire the night before the pedometers were collected. This alerted researchers to times during the monitoring period that parents or caregivers were aware their children had removed the pedometer. Although this method is less effective for detecting noncompliance when parents or caregivers are not present, the low reliability of self-report techniques in children (23) precluded their use in this study. Noncompliance during school hours was considered negligible because of active teacher assistance. At present, a standard noncompliance time period above which pedometer data are discarded has yet to be established. Data treatment procedures used in previous studies have ranged from the inclusion of all daily pedometer data regardless of participant compliance (29) to the exclusion of data from participants who removed their pedometer for more than 1 h on any given day (36). Although the latter criterion results in a greater number of exclusions, it likely provides the most accurate estimates of daily steps. Thus, children in the present study who removed their pedometer for more than 1 h on any given day had the steps accumulated on that day omitted from analysis. Participants were excluded from the study if more than one weekday and one weekend day were lost because of incomplete data.

Nevertheless, the possibility that noncompliant individuals were overlooked because of inaccurate parent or caregiver questionnaires cannot be ruled out. Of particular concern is the potential for abnormally low or high step counts to be retained in the dataset. To date, limited information exists concerning the treatment of extreme values in pedometry research. The only existing standards for children were developed by Rowe et al. (20), using a combination of percentile analysis and previous experience. It was proposed that daily step counts below 1,000 or above 30,000 were unlikely to be valid and should be regarded as outliers. Five participants (0.4%) from the present study were excluded by these criteria.

Body composition. The standing height of each participant was measured to the nearest millimeter with a portable stadiometer (Design No. 1013522, Surgical and Medical Products, Seven Hills, Australia), and weight was measured to the nearest 0.1 kg on a digital scale (Model Seca 770, Seca, Hamburg, Germany). BMI was then calculated as weight (kg) divided by squared height (m^2). During data analysis, participants were classified as normal weight, overweight, or obese using international age- and sex-specific BMI cutoff points (4). In addition, WC measurements were made at the highest point of the iliac crest at minimal respiration. Children with a central pattern of fat distribution were identified using the WC cutoffs developed for New Zealand children by Taylor et al. (28).

Body fat measurements were obtained using hand-to-foot bioelectrical impedance analysis (BIA). Resistance (R) was measured at 50 kHz using a bioimpedance analyzer (Model BIM4, Impedimed, Capalaba, Australia) with a tetrapolar arrangement of self-adhesive electrodes (Red Dot 2330, 3M Healthcare, St. Paul, MN). After swabbing the skin on the right hand and foot with alcohol, source electrodes were placed on the dorsal surface of the foot over the distal portion of the second metatarsal and, on the hand, on the distal portion of the second metacarpal. Sensing electrodes were placed at the anterior ankle between the tibial and the fibular malleoli, and at the posterior wrist between the styloid processes of the radius and ulna. Testing was initiated after the participants emptied their bladder and had been lying supine with their arms and legs abducted for at least 5 min. Testing was completed when repeated measurements of R were within 1 Ω of each other. Fat-free mass (FFM) was then calculated from R, height, and weight using a prediction equation previously validated with deuterium dilution ($R^2 = 0.96$, SEE = 2.44 kg) in New Zealand children (22). To ensure consistency between samples, preparation procedures in the present study were identical to those implemented by Rush et al. (22). Fat mass (FM) was derived as the difference between FFM and body weight. Percentage body fat was calculated as 100 × FM/weight. Children above the 90th percentile of %BF for each age- and sex-specific group in the sample were classified as having excessive body fatness. Unlike BMI, no generally accepted definitions exist of overweight or obesity in children based on %BF. Given that approximately 10% of New Zealand children are classified as obese using international BMI thresholds (17), the 90th percentile of %BF was chosen as the cutoff point for identifying excessively high levels of body fatness in this sample.

Statistical analyses. Data were analyzed using SPSS version 12.0.1 for Windows (SPSS Inc., Chicago, IL). Differences in participant characteristics (age, height, weight, BMI, WC, and %BF) between sexes and among ethnic groups were assessed by two-way ANOVA, and significant associations were examined by pairwise comparisons using *t*-tests. One-way ANOVA and Bonferroni *post hoc* tests were used to determine where significant differences in step counts existed among ethnic, age, socioeconomic, BMI, WC, and %BF groups. Associations among weekday and weekend step counts, sex, ethnicity, and %BF category were assessed using factorial repeated-measures ANCOVA (sex by ethnicity by %BF by day) with age and SES as covariates. A P value < 0.05 was used to indicate statistical significance.

RESULTS

The physical characteristics of each ethnic group in this study are presented in Table 1. Although no significant effects were found of sex on age, height, weight, BMI, or WC, significant differences in %BF were detected between boys and girls within each ethnic group (excluding other ethnicities). Furthermore, Polynesian children were heavier than European and Asian children and had a greater BMI and WC. Ethnic differences in %BF were also observed, with Polynesian and Asian boys carrying significantly

TABLE 1. Participant characteristics (mean ± SD).

	European		Polynesian		Asian		Other Ethnicities	
	M (*N* = 266)	F (*N* = 283)	M (*N* = 159)	F (*N* = 175)	M (*N* = 92)	F (*N* = 92)	M (*N* = 19)	F (*N* = 29)
Age (yr)	8.2 ± 1.7	8.4 ± 1.7	8.5 ± 1.8	8.5 ± 1.8	8.7 ± 1.6	8.7 ± 1.7	8.8 ± 1.8	8.6 ± 1.8
Height (cm)	131.0 ± 12.0	130.9 ± 11.8	133.9 ± 12.6	133.8 ± 13.2	130.9 ± 9.8	130.7 ± 12.3	133.4 ± 10.8	130.6 ± 9.8
Weight (kg)	29.9 ± 8.6†	30.4 ± 9.7†	36.4 ± 13.5	36.4 ± 14.4	30.3 ± 8.2†	29.7 ± 9.3†	30.6 ± 7.8	29.5 ± 7.8*
BMI (kg·m^{-2})	17.1 ± 2.4†	17.3 ± 2.8†	19.7 ± 4.5	19.6 ± 4.5	17.4 ± 2.8†	17.0 ± 2.9*	17.0 ± 2.6*	17.0 ± 2.6*
WC (cm)	59.7 ± 7.8†	59.9 ± 7.9†	65.3 ± 11.6	64.4 ± 11.7	60.9 ± 8.5†	59.0 ± 8.4†	60.5 ± 6.5	58.0 ± 6.9†
Body fat (%)	17.5 ± 6.0†‡§	21.2 ± 6.4*	21.0 ± 7.7§	23.3 ± 7.2	20.3 ± 6.9§	23.2 ± 7.7	20.2 ± 7.2	22.7 ± 6.1

BMI, body mass index; WC, waist circumference; M, male; F, female.
* Significantly different from Polynesian of same sex ($P < 0.05$).
† Significantly different from Polynesian of same sex ($P < 0.005$).
‡ Significantly different from Asian of same sex ($P < 0.005$).
§ Significantly different from female of same ethnicity ($P < 0.005$).

more body fat than their European counterparts. Similar %BF trends were found in girls, although the difference between the European and Asian groups was not significant ($P = 0.108$).

Table 2 shows the mean weekday and weekend step counts for the study sample grouped according to sex, ethnicity, age, socioeconomic status, BMI, WC, and %BF. Mean weekday steps were consistently higher and had smaller standard deviations than mean weekend steps across all subgroups. Preliminary analysis revealed significant differences in weekday steps between boys and girls and among the three major ethnic groupings, with Polynesian children the most active and Asian children the least active during weekdays. Weekend activity showed similar patterns between sexes and among ethnicities, although European children averaged the highest weekend step count. Weekend activity decreased with age and increased with socioeconomic status, trends that were not observed for weekday activity.

The relationships between mean step counts and each of the three body composition variables included in this study were analyzed separately. First, international BMI cutoff points for childhood overweight and obesity (4) were applied to the sample. Overall, 73.5% of participants were classified as "normal" weight, with 17.3% overweight and a further 9.2% obese. Analysis of variance showed a significant difference in weekend, but not weekday ($P = 0.291$), step counts among the three BMI categories (Table 2). Participants were then grouped according to the WC standards proposed by Taylor et al. (28). Compared with BMI, differences in activity between children with normal fat distribution (78.4%) and those with central fat distribution (21.6%) were larger for weekdays and similar for weekends. Finally, the greatest differences in steps per day

TABLE 2. Pedometer-determined physical activity (steps per day).

	Weekday Steps		Weekend Steps	
	N	Mean ± SD	*N*	Mean ± SD
Total	1074	15,085 ± 3,711	1011	11,886 ± 4,733
Sex†‡				
Male	514	16,132 ± 3,864	477	12,702 ± 5,048
Female	560	14,124 ± 3,286	534	11,158 ± 4,309
Ethnicity†‡				
European	526	15,072 ± 3,459	504	12,302 ± 4,591
Polynesian	322	15,747 ± 4,185	291	11,836 ± 5,257
Asian	180	14,134 ± 3,570	172	10,925 ± 4,221
Other	46	14,328 ± 2,412	44	11,214 ± 4,016
Age (yr)‡				
5–6	183	15,284 ± 3,311	164	12,948 ± 4,551
7–8	360	15,201 ± 3,404	337	12,612 ± 4,855
9–10	363	15,003 ± 4,019	352	11,250 ± 4,525
11–12	168	14,801 ± 4,055	158	10,656 ± 4,653
Socioeconomic status‡				
Low	372	15,264 ± 3,965	345	11,004 ± 4,792
Middle	313	14,780 ± 3,406	292	12,112 ± 4,660
High	389	15,160 ± 3,690	374	12,525 ± 4,624
BMI (kg·m^{-2})*‡				
Normal weight	789	15,151 ± 3,554	746	12,185 ± 4,713
Overweight	188	15,098 ± 4,169	172	11,139 ± 4,450
Obese	97	14,524 ± 4,002	93	10,872 ± 5,142
Waist circumference**¶§				
Normal fat distribution	838	15,190 ± 3,612	790	12,101 ± 4,701
Central fat distribution	231	14,638 ± 4,001	215	11,152 ± 4,762
Percentage body fat†§				
< 90th percentile	961	15,235 ± 3,693	906	12,028 ± 4,739
≥ 90th percentile	104	13,750 ± 3,652	97	10,693 ± 4,629

* Classified by international age- and sex-specific BMI cutoff points (4).
** Classified by the WC cutoff points proposed by Taylor et al. (28).
† Significantly different for weekday steps ($P < 0.005$).
‡ Significantly different for weekend steps ($P < 0.005$).
¶ Significantly different for weekday steps ($P < 0.05$).
§ Significantly different for weekend steps ($P < 0.05$).

TABLE 3. Factorial repeated-measures ANCOVA (sex by ethnicity by %BF by day) corrected for age and SES.

Source	F	P
Within subjects		
Day	18.233	0.000†
Day × age	16.727	0.000†
Day × SES	9.850	0.002†
Day × sex	4.173	0.041*
Day × ethnicity	0.087	0.917
Day × %BF	0.513	0.474
Day × sex × ethnicity	0.142	0.867
Day × sex × %BF	0.023	0.879
Day × ethnicity × %BF	1.138	0.321
Day × sex × ethnicity × %BF	1.116	0.328
Between subjects		
Age	16.162	0.000†
SES	8.383	0.004†
Sex	13.428	0.000†
Ethnicity	5.812	0.003†
%BF	13.523	0.000†
Sex × ethnicity	0.457	0.633
Sex × %BF	1.765	0.184
Ethnicity × %BF	0.570	0.566
Sex × ethnicity × %BF	0.217	0.805

* Significant (P < 0.05) level.
† Significant (P < 0.005) level.
%BF, percent body fat; SES, socioeconomic status.

were found when participants were categorized into either normal (< 90th percentile) or high (> 90th percentile) %BF groups. Both weekday and weekend activity was significantly lower for children with high %BF (9.5%) when compared with those with normal %BF levels (90.5%).

To investigate the interaction among the key factors associated with activity in this sample, sex (male and female), ethnicity (European, Polynesian, and Asian), %BF (normal %BF and high %BF), and day (weekday and weekend) were entered into a 2 × 3 × 2 × 2 factorial repeated-measures ANCOVA (sex by ethnicity by %BF by day) with age and SES as covariates (Table 3). Mean step counts differed significantly between weekdays and weekends, with significant interactions between day and age, day and socioeconomic status, and day and sex. No significant interactions existed between day and ethnicity, day and %BF, or among any of the higher-level combinations. This indicates that the significant decrease in activity observed on weekend days is affected by age, socioeconomic status, and sex, but not by ethnicity or %BF category. Analysis of the between-subject variance revealed significant associations between overall mean step count and both age and SES. Significant differences between boys and girls, among ethnicities, and between %BF groups were also detected. The latter finding, in addition to the nonsignificance of the interaction between day and %BF, shows that a high level of %BF (> 90th percentile) is associated with a significantly lower number of daily steps on both weekdays and weekends. Furthermore, the nonsignificant interactions among sex, ethnicity, and %BF indicate that the negative association between %BF status and daily steps is similar for boys and girls from all ethnic groups.

Figure 1 shows the differences in weekday and weekend step counts between %BF groups for all ethnicities. On average, boys with normal %BF levels accumulated 1554 more steps each weekday and 1893 more steps each weekend than boys with high %BF. Girls with normal %BF levels achieved 1480 more steps each weekday but only 844 more steps each weekend when compared with those in the high %BF group. The Cohen effect size statistics associated with these differences were 0.40 for boys and 0.47 for girls on weekdays, and 0.40 for boys and 0.19 for girls on weekends. This implies that %BF status had a moderate association with mean weekday and weekend steps in boys, a slightly larger association with mean weekday steps in girls, and a trivial association with mean weekend steps in girls.

DISCUSSION

The results presented in this study represent the only step count data available for young New Zealanders and have enabled us to observe the physical activity patterns of New Zealand children from an international perspective for the first time. Previous research from a large three-country sample found that Swedish children were the most active on weekdays (15,673–18,346 steps per day for boys, and 12,041–14,825 steps per day for girls), followed by Australian children (13,864–15,023 and 11,221–12,322 steps per day), and then American children (12,554–13,872 and 10,661–11,383 steps per day) (34). Comparing these

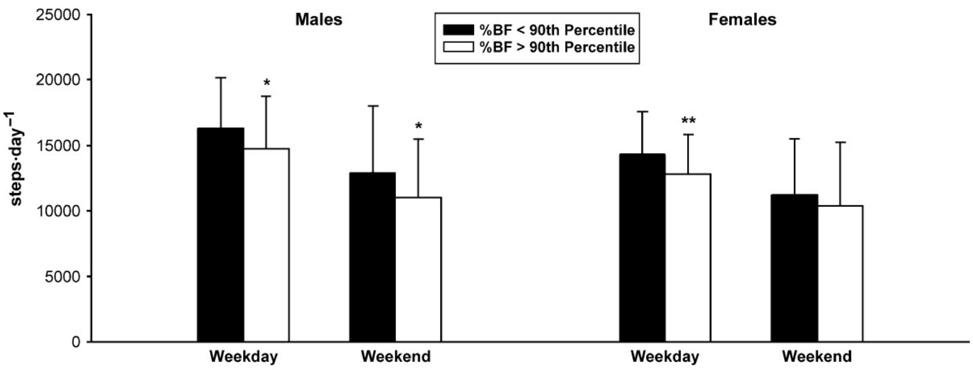

FIGURE 1—Pedometer-determined physical activity during weekdays and weekends grouped by sex and %BF. * **Significant (P < 0.05) level.** ** **Significant (P < 0.005) level.**

data with findings from the present study suggests that New Zealand children are relatively active, with boys averaging 16,133 steps and girls averaging 14,124 steps each weekday. It should be noted, however, that such comparisons of physical activity levels do not necessarily reflect the overall variation between countries because neither dataset is representative. The potential measurement error between different brands of pedometer may be another confounding factor (15).

The mean step counts recorded on weekends were significantly lower than on weekdays in our sample (boys, 12,702; girls, 11,158), with the extent of the decrease dependent on participant age, sex, and socioeconomic status. This may be a result of greater opportunities to participate in active play, sport, or physical education programs when at school, and suggests that the promotion of activity during out-of-school hours is a priority. However, previous comparisons of weekday and weekend activity using other measures of physical activity in children have been equivocal. Trost et al. (30) found that children accumulated more accelerometer counts on weekends compared with weekdays. In contrast, Gavarry et al. (10) used heart rate monitoring to show a significant decrease in children's activity during free days. The latter authors proposed that social and cultural factors may be responsible for the discrepancies among studies. An understanding of the types of activity occurring at school and at home may help explain such differences. To our knowledge, only one other study used pedometers to investigate weekend activity in children (20). Although the mean weekday step count (9504) was slightly greater than the mean weekend step count (9005), data were collected by the participants using various self-report techniques that have yet to be validated. Consequently, it is difficult to establish whether the difference in weekday and weekend steps demonstrated in the present study is distinctive to New Zealand children.

Significant differences in activity were also observed between sexes, with boys 14.2 and 13.8% more active than girls on weekdays and weekends, respectively. This was not surprising because sex is the most frequent correlate of physical activity identified in previous research (24). Our step count data also showed a negative association with age on weekends but not on weekdays. Although convincing evidence indicates an age-related decline in physical activity during adolescence, data representing preadolescent children are less consistent (24). Trost et al. (31) reported a significant decrease in accelerometer counts during both childhood and adolescence. Conversely, Vincent et al. (34) found little effect of age on weekday step counts in their international cohort of children 6–12 yr of age. This was supported by recent findings suggesting that a significant decline in weekday steps occurs during the transition from elementary school to high school (14). Combining the latter findings with those from the present study, it seems likely that the number of steps accumulated by preadolescent children on weekdays is relatively constant. The divergence from previous accelerometry data may be a result of differences in methodology. For example, an age-related decline in nonambulatory activity (e.g., cycling, swimming, or other upper-body movement) would be detected by accelerometry but not by pedometry. In any case, our results suggest that age-related trends in physical activity behavior may be accentuated in out-of-school environments. Similarly, grouping the sample by socioeconomic status revealed significant differences in weekend steps only. This is of interest because most previous research has found little evidence of an interaction between physical activity and socioeconomic indicators in children (24). A possible explanation is that New Zealand schools are required to maintain a reasonable level of physical activity regardless of socioeconomic rating, whereas children from more privileged backgrounds may be given greater opportunity to be active during weekends. Thus, interventions that focus on promoting out-of-school activity in families from lower socioeconomic regions may be beneficial.

Although the mean weekday step counts in the present study appear higher than current international estimates (34), the prevalence of overweight and obesity in the Australian and Swedish children (15.1 and 16.7%, respectively) was considerably lower than in our sample (26.5%). This apparent paradox may be explained by the relatively weak correlations between BMI and steps per day. Our results showed trends similar to those reported by Vincent et al. (34), with no significant differences in weekday step counts among the three BMI categories. This may be partly attributable to the limitations of BMI as a tool for measuring childhood obesity. Previous research has raised the possibility of interindividual variance in %BF at a given BMI among children from different ethnic backgrounds (8). Consequently, the use of a universal BMI scale for classifying overweight and obesity may not be appropriate for children who differ from the typical European phenotype. Polynesian children, for instance, tend to have more FFM and less FM at a given BMI when compared with European children (22). In contrast, Asian children often show less FFM and more FM than their European counterparts (8). Although the degree of potential misclassification for each ethnic group is uncertain, it is likely that the trivial associations between mean step count and BMI status observed in this study reflect the shortcomings of BMI as a predictor of childhood obesity.

A key objective of this study was to determine whether the implementation of body composition measures other than BMI would enable the detection of an association between steps per day and childhood obesity. It is well established that central adiposity increases the risk of several negative health outcomes in childhood (7). By grouping the sample according to the WC cutoffs proposed by Taylor et al. (28), we were able to compare step counts in children with normal and central patterns of fat distribution. Results showed that children with central adiposity averaged significantly fewer steps on weekdays and weekends than those with normal fat distribution. This is consistent with recent research suggesting that WC has stronger associations with physical activity in young people than BMI (12). As with BMI, however, it remains possible that ethnic variation in body size may contribute to the potential misclassification of Polynesian and Asian children. The development of ethnic-specific cutoffs may address this issue.

Percentage body fat provides a more appropriate gauge of obesity than either BMI or WC. Criterion measures of body fat (e.g., dual-energy x-ray absorptiometry, deuterium dilution, and underwater weighing) are costly and impractical for large-scale research. However, these reference standards can be used to calculate accurate ($R^2 > 0.95$) BIA prediction equations for describing %BF in children. BIA is an ideal technique for pediatric populations because of its portability and short operating time (5–10 min). It is also less invasive and has greater interrater reliability than skinfold testing, a common measure of body fat used in field studies. The main limitation of BIA is that the study sample must be comparable with the reference population from which the prediction equation was derived. Using a BIA equation cross-validated with deuterium dilution in New Zealand children, we found significant associations between the numbers of steps children accumulated each day and their level of body fatness. Boys and girls with excessive body fat averaged 1554 and 1893 fewer steps, respectively, each weekday than children with normal body fat levels. Although the differences were less pronounced on the weekends (1480 and 844 for boys and girls, respectively), the significant association between %BF status and activity was similar across sexes and ethnic groups. This provides new evidence supporting the implementation of population-wide initiatives for increasing daily steps in children. Nevertheless, the cross-sectional design of this study precludes statements of cause and effect. A logical next step is to obtain longitudinal data monitoring trends in steps per day and body fatness during development. This would enable conclusions to be made regarding the causal nature of the relation between steps and body fat in children. The effect of puberty on the association between daily step counts and body fatness also requires investigation. The sharp decline reported previously (14) in steps per day during the transition from childhood to adolescence coincides with distinct changes in body composition. For example, at an equivalent BMI, adolescents who are sexually mature tend to have a lower %BF than those who are less developed (6). Resolving the relationships between pedometer-determined activity and population measures of body composition at various stages of maturation is an important topic for future research.

Given the findings from the present study, we suggest that daily step count targets based on %BF are more relevant than either BMI- or WC-referenced standards. Currently, the only step count recommendations available for young people are based on BMI. Tudor-Locke et al. (32) proposed a target of 15,000 (boys) and 12,000 (girls) steps each weekday to minimize the risk of overweight or obesity as defined by international BMI cutoff points (4). Before these step count standards can be verified using %BF, the levels of body fat that constitute an unhealthy child need to be determined. The development of sex- and age-specific %BF charts identifying increased health risk in young people would ensure that %BF-referenced step count targets are applicable to the population. Prospective recommendations should also allow for the significantly lower step counts on weekends when compared with weekdays. Yet another layer of complexity is added when considering the potential differences in activity and body composition across ethnic groups within a population. Our results indicated that Asian children were the least active of the three ethnic groups in this study, whereas Polynesian children were the most active on weekdays. Interestingly, both Asian and Polynesian groups had relatively high levels of body fat compared with Europeans. The high weekend step counts observed in European children may be related to the larger proportion of this ethnic group with a high socioeconomic rating (51.0%) when compared with Asian (42.3%) and Polynesian (8.4%) children. Such ethnic variation, although an important consideration when tailoring obesity-prevention initiatives, may not be practical to include in population step count recommendations.

In summary, this study provides the first step count data for young New Zealanders, revealing differences in physical activity across sex, age, and socioeconomic groups, and among European, Polynesian, and Asian children. The utilization of MDM pedometers enabled us to detect significantly lower levels of activity during weekends when compared with weekdays. Furthermore, the results of this study offer new evidence of a link between daily steps and body fatness in children. Given that daily steps were more strongly related with body fat than either BMI or WC, we recommend the use of %BF as an indicator of childhood obesity in physical activity research. These findings advance the current state of knowledge regarding physical activity and body composition in children and provide support for the development of strategies to increase the accumulation of daily steps in pediatric populations.

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Step count recommendations for children based on body fat

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Abstract

Objective. Current recommendations for pedometer-determined physical activity in children (boys, 15,000 steps/day; girls, 12,000 steps/day) were based on the association between weekday step counts and body mass index. The objective of this study was to develop new targets using both weekday and weekend step counts with percentage body fat (%BF) as the criterion reference.

Method. The %BF of 969 New Zealand European, Polynesian, and Asian children (515 male, 454 female) aged 5 12 years was measured in 2004 using hand-to-foot bioelectrical impedance analysis. Weekday and weekend step counts, assessed using sealed multi-day-memory pedometers over 5 days, were combined into a scaled mean step count. The contrasting groups method for determining criterion-referenced cut-off points was used to establish the optimal step count values for predicting overweight (%BF > 85th percentile) and non-overweight (%BF < 85th percentile).

Results. Overweight children had significantly lower mean step counts (14,238 ± 3343, boys; 12,555 ± 3169, girls) than non-overweight children (16,106 ± 3208, boys; 14,176 ± 2728, girls). Optimal step count cut-off points were 16,000 steps/day for boys and 13,000 steps/day for girls.

Conclusion. Step count targets for reducing the risk of excess body fat in children are 1000 steps/day higher than existing BMI-referenced guidelines.

Keywords: Exercise; Adiposity; Body mass index; Overweight; Obesity; Child

Introduction

Regular physical activity provides numerous health benefits for people of all ages (US Department of Health and Human Services, 1996). As such, the promotion of habitual activity has become a key public health priority in many countries. Step-counting pedometers are an effective motivational tool in this regard, offering an inexpensive and straightforward means to monitor the accumulation of daily activity (Sirard and Pate, 2001). In order to guide pedometer-based surveillance and interventions, daily step count targets related to positive health outcomes are essential. In adults, 10,000 steps/day has gained acceptance as an appropriate public health message for reducing the risk of overweight (Tudor-Locke and Bassett, 2004). However, children average significantly greater levels of activity than adults regardless of their body size (Duncan et al., 2006), suggesting that higher step count targets are required.

Tudor-Locke et al. (2004) recently used body mass index (BMI) as a criterion for developing pedometer-determined activity recommendations in children. Daily step count targets of 15,000 (boys) and 12,000 (girls) were proposed as the optimal cut-off points for predicting normal and overweight BMI. Subsequent evidence suggests that step counts are more strongly associated with percentage body fat (%BF) than with BMI in children (Duncan et al., 2006). This is not surprising given that BMI does not distinguish between lean and fat mass, and provides a less direct estimate of adiposity than %BF (World Health Organization, 1995). Furthermore, existing guidelines were developed from weekday steps only. Previous pedometry studies in children have observed significantly fewer steps on weekend days than on weekdays (Duncan et al., 2006; Rowe et al., 2004). Given that step count targets are applicable on weekdays and weekends, it is important to consider differences in activity between these days during the development process.

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Table 1
Daily step counts for children aged 5–12 years stratified by BMI and %BF status

Measure	Sex	Non-overweight steps/day	Overweight steps/day
BMI	Male	15,205±3490 (117)	14,750±3704 (117)
	Female	13,294±3420 (137)	13,198±3420 (137)
%BF	Male	16,106±3208 (72)	14,238±3343 (72)*
	Female	14,176±2728 (74)	12,555±3169 (74)*

Data are presented as mean± SD with sample sizes in parentheses.
* Significantly different Non-Overweight ($P<0.005$).

The purpose of this study was to replicate the analyses undertaken by Tudor-Locke et al. (2004) using both weekday and weekend step count data with %BF as the criterion reference. This will provide new step count targets more closely related to health outcomes than current recommendations.

Methods

Participant recruitment and data collection procedures are described in detail elsewhere (Duncan et al., 2006). Briefly, 969 children (454 boys, 515 girls) aged 5–12 years were randomly selected from 27 elementary schools in Auckland, New Zealand. The ethnic composition of the sample was 49.6% European (228 boys, 253 girls), 28.7% Polynesian (128 boys, 150 girls), 17.3% Asian (81 boys, 87 girls), and 4.3% from other ethnicities (17 boys, 25 girls). Ethical approval was obtained from our institutional ethics committee. Each participant and their legal guardian provided written informed consent.

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 squared height (m^2). Resistance measurements were obtained using a hand-to-foot bioelectrical impedance analyzer (Model BIM4, Impedimed, Capalaba, Australia) with a tetrapolar arrangement of self-adhesive electrodes (Red Dot 2330, 3M Healthcare, St Paul, MN, USA). A prediction equation previously validated with deuterium dilution in New Zealand children aged 5–14 years (R^2=0.96, SEE=2.44 kg) was used to derive fat-free mass (FFM) from resistance, height, and weight (Rush et al., 2003). %BF was then calculated as the difference between weight and FFM divided by weight and multiplied by 100. Overweight (including obese) children were classified according to international BMI cut-off points (Cole et al., 2000) and the 85th percentile of %BF for each age and gender group. The latter criterion was chosen as it provides the closest approximation to the overweight boundaries of international BMI curves (McCarthy et al., 2006).

Habitual physical activity was measured using sealed multi-day-memory pedometers (Model NL-2000, New Lifestyles Inc., Lee's Summit, MO) over three weekdays and two weekend days. An overall mean step count was obtained after scaling the averaged data by a ratio of five weekdays to two weekend days. Data were excluded if participants did not wear the pedometer for more than one hour on a given day (as determined by a parent proxy questionnaire). Daily step counts below 1000 or above 30,000 were regarded as outliers and were removed (Rowe et al., 2004).

The difference in mean step counts between overweight and non-overweight children was examined separately for BMI and %BF using two-tailed independent samples *t*-tests. Each analysis sample was divided into overweight children and a random selection of age- and gender-matched non-overweight children. The contrasting groups method for determining criterion-referenced cut points, described previously by Tudor-Locke et al. (2004), utilize several statistical approaches to establish the predictive ability of a given cutting score: (1) probability of correct decisions; (2) misclassification errors; (3) validity coefficient; and (4) utility analysis. The value of each index was calculated for a range of potential step count targets in order to determine the optimal cut-off point. Data were analyzed using SPSS version 12.0.1 for Windows (SPSS Inc., Chicago, IL).

Results

Table 1 shows the mean scaled step counts for boys and girls grouped by BMI and %BF status. The prevalence of overweight was 22.7% (BMI) and 14.0% (%BF) for boys, and 30.2% and

Table 2
Determination of optimal step count cut-off points for boys and girls aged 5–12 years using the contrasting groups method for determining criterion-referenced standards

Steps/day	Probability of correct decisions	Misclassification errors (type I/type II)	Validity coefficient	Utility analysis		
				Expected utility	Expected disutility	Expected maximum utility
Male						
10,000	0.53	0.01/0.45	0.14	0.53	−0.47	10
11,000	0.57	0.02/0.41	0.22	0.57	−0.43	20
12,000	0.58	0.05/0.38	0.20	0.58	−0.42	22
13,000	0.58	0.08/0.33	0.19	0.58	−0.42	24
14,000	0.61	0.13/0.26	0.23	0.61	−0.39	32
15,000	0.60	0.20/0.20	0.19	0.60	−0.40	28
16,000[a]	0.62	0.26/0.13	0.24	0.62	−0.38	34
17,000	0.60	0.30/0.10	0.23	0.60	−0.40	30
18,000	0.57	0.37/0.06	0.18	0.57	−0.43	20
Female						
10,000	0.59	0.03/0.37	0.26	0.59	−0.41	28
11,000	0.59	0.06/0.35	0.22	0.59	−0.41	26
12,000	0.60	0.13/0.27	0.21	0.60	−0.40	30
13,000[a]	0.65	0.16/0.20	0.30	0.65	−0.35	44
14,000	0.61	0.22/0.17	0.22	0.61	−0.39	32
15,000	0.62	0.28/0.10	0.26	0.62	−0.38	36
16,000	0.55	0.37/0.07	0.13	0.55	−0.45	16
17,000	0.52	0.43/0.05	0.06	0.52	−0.48	6
18,000	0.51	0.46/0.03	0.03	0.51	−0.49	2

[a] Optimal step count cut-off point.

16.3% for girls. Children classified as overweight using %BF had significantly lower step counts than their non-overweight counterparts. No significant differences in step counts were observed between BMI categories.

A summary of the contrasting groups method for determining %BF-referenced step count targets is presented in Table 2. The optimal step count cut-off points for predicting %BF status were 16,000 steps/day for boys and 13,000 steps/day for girls.

Discussion

This study provides the first opportunity to assess the appropriateness of the BMI-referenced step count guidelines for children proposed by Tudor-Locke et al. (2004). The collection of both weekday and weekend steps with %BF as the criterion reference enabled us to investigate the predictive ability of a series of prospective cut-off points. Our results indicate that existing guidelines (15,000 step/day for boys, 12,000 steps/day for girls) are reasonable targets for children. However, cut points of 16,000 and 13,000 steps/day were the best predictors of body fat status in this sample, and therefore an increase of 1000 steps/day for boys and girls aged 5–12 years should be considered. Previous research suggests that 1000 steps is a worthwhile increase in daily activity with respect to improving health outcomes (Tudor-Locke et al., 2004).

The variation in results between studies may be explained by the different techniques used to measure and define overweight. There is substantial evidence that BMI is a mediocre indicator of overweight in children from non-European ethnic groups (Deurenberg et al., 2003; Rush et al., 2003). Indeed, there were no significant relationships between BMI status and steps/day in our multiethnic sample. In addition, daily recommendations that do not account for a reduction in steps on weekend days (Duncan et al., 2006; Rowe et al., 2004) may overestimate the level of activity required for health benefits. To avoid this potential source of error, we transformed weekday and weekend data into a scaled average that reflected the overall contribution of each day type to weekly activity. An alternative would be to issue discrete guidelines for weekdays and weekend days; however, this option may be unnecessarily complicated for health promotion purposes.

It should also be noted that Tudor-Locke et al. (2004) collected data from predominantly European communities in Australia, Sweden, and the USA. Thus, the divergence from our results may also be attributable to differences in population characteristics. The positive associations between steps/day and BMI in their international cohort were not observed in our sample, suggesting that at least some differences do exist. Population-specific step count guidelines may be warranted if the relationship between body fatness and physical activity also varies between countries or ethnicities. It is clear that this issue requires further investigation.

In summary, our results confirm that daily step count guidelines for children should be set considerably higher than those for adults. Based on %BF status, we propose targets of 16,000 and 13,000 steps/day for boys and girls (respectively). This corresponds to a 1000 steps/day increase over existing BMI-referenced guidelines.

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Original Article

Risk factors for excess body fatness in New Zealand children

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Objective: To identify demographic and lifestyle risk factors for excess body fatness in a multiethnic sample of New Zealand children. **Design:** Cross-sectional study. **Participants:** A total of 1229 European, Polynesian, Asian, and 'Other' children aged 5-11 y (603 male, 626 female) living in New Zealand. **Measurements:** Percentage body fat (%BF) was measured using hand-to-foot bioelectrical impedance analysis, and overfat participants were defined as those with a %BF greater than 25% (boys) and 30% (girls). A parent proxy questionnaire was developed for assessing demographic and lifestyle factors, and multiday memory pedometers were used to estimate physical activity levels over five days. **Results:** After controlling for differences in sex, age, and socioeconomic status (SES), Asian children were more likely to have excess body fat than European children. The adjusted odds of overfat also increased with age and decreased with SES. Three lifestyle risk factors related to fat status were identified: low physical activity, skipping breakfast, and insufficient sleep on weekdays. Clustering of these risk factors resulted in a cumulative increase in the prevalence of overfat. Active transport, sports participation, lunch bought at school, fast food consumption, sugary drink consumption, and weekend sleep duration were not associated with fat status after adjustment for the selected demographic variables. **Conclusion:** The findings from this study enhance our understanding of the risk factors for excess body fatness in New Zealand children, and highlight key demographic and lifestyle priorities for future interventions.

Key Words: obesity, ethnicity, diet, physical activity, sleep

INTRODUCTION

The prevalence of overweight and obesity in children has reached epidemic proportions in many countries. Given the long-term economic and public health consequences associated with childhood obesity, the development of preventative strategies for reducing the accretion of excess fat in young people is essential. However, obesity is a complex disorder that is modulated by interactions between environmental and behavioral factors, and consequently isolating the key predictors of obesity in young people can be challenging.

Potential risk factors for obesity are commonly categorized as either demographic (non-modifiable) or lifestyle (modifiable) factors. An understanding of the demographic risk factors related to obesity can help prioritize the population groups to be targeted by public health initiatives. For example, there is evidence that the prevalence of childhood obesity in developed countries is relatively high among certain ethnic minorities[1-3] and in those from underprivileged backgrounds.[4-6] Nonetheless, the interplay between socioeconomic status (SES) and ethnicity and their effects on obesity remain unclear. It has been hypothesized that the high occurrence of obesity in some ethnic minorities is due to their overrepresentation in low socioeconomic regions.[7] Subsequent research suggests that SES is not the only contributor to ethnic differences in childhood obesity, but that other ethnic-specific variables (e.g., body composition, culture, maturation) may have important roles.[8-10]

While demographic risk factors are useful for isolating the population groups most susceptible to obesity, lifestyle factors reflect the underlying behaviors that promote excessive fat accumulation. A wide range of potential lifestyle risk factors for childhood obesity have been investigated with variable results.[11] The most consistent predictors of obesity in children are low levels of physical activity,[12-15] unhealthy dietary patterns,[16-20] and insufficient sleep.[4,21-23] However, there is limited information describing the interactions among multiple risk factors and their cumulative (or confounding) effects on children's adiposity. The only study to address this issue investigated overweight and obesity in German children aged 5-7 years with various combinations of three demographic risk factors (parental overweight, low SES, and high birth weight).[5] On average, children that had two risk factors were more likely to be overweight or obese

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than those with single risk factors, with the highest prevalence values observed when all three risk factors were combined. The potential effects of clustering modifiable risk factors have yet to be assessed.

Further complications arise when the different methods used to classify obesity in children are considered. Most previous studies have used age- and sex-specific body mass index (BMI) percentiles to define obesity. This is despite evidence that BMI may not provide an equivalent estimate of body fatness across different ethnic groups due to its inability to distinguish between fat and fat-free mass.[24,25] Furthermore, the relationship between the BMI percentiles used to define childhood obesity and negative health outcomes is uncertain. As such, risk factors for BMI-determined obesity may not necessarily correspond to a higher risk of morbidity. Several studies have proposed sex-specific percentage body fat (%BF) limits ranging from 20% to 30% that coincide with elevated risk of health complications in children.[26-28] These health-related %BF criteria may provide more relevant reference points for determining obesity risk factors than existing BMI standards.

It is clear that an awareness of the factors associated with excessive fat accrual in children is essential to counteract the current obesity trends. Despite evidence that the average BMI of young New Zealanders is rapidly increasing,[29] there is no information describing the predictors of body fatness in this population. Thus, the primary objective of this study was to identify key demographic and lifestyle factors associated with increased risk of excess adiposity in a multiethnic sample of New Zealand children. A secondary objective was to examine the effects of risk factor clustering on the prevalence of overfat in children.

METHODS

Participants

A total of 1 229 children (603 boys, 626 girls) aged 5-11 years were randomly selected from 27 primary (elementary) schools in Auckland, New Zealand. Participating schools were purposively sampled to replicate the geographic and socioeconomic distribution of primary schools in the Auckland district. The ethnic composition of the sample was 46.8% European (283 boys, 292 girls), 33.1% Polynesian (201 boys, 206 girls), 15.9% Asian (99 boys, 97 girls), and 4.1% from other ethnicities (20 boys, 31 girls). The Polynesian ethnic group composed of Pacific Island (58.2%) and Maori (41.8%) children, and the Asian group composed of Indian (38.3%), Chinese (21.9%), Korean (13.8%), Filipino (9.7%), Sri Lankan (4.1%), and Other Asian (12.2%) children. SES was estimated using the Ministry of Education decile classification system for New Zealand primary schools. For the purposes of this study, participants from schools with a decile rating between 1 and 3 were categorized into the 'Low' SES group, and those from schools rated between 4 to 7 and between 8 to 10 were considered 'Middle' and 'High', respectively. Ethical approval for this study was obtained from the Auckland University of Technology ethics committee. Written informed consent was provided by each participant and his or her legal guardian.

Measurements and procedures

The height of each participant was measured to the nearest millimeter with a portable stadiometer (Design No. 1013522, Surgical and Medical Products, Seven Hills, Australia), and weight was assessed to the nearest 0.1 kg on a digital scale (Model Seca 770, Seca, Hamburg, Germany). Body mass index (BMI) was calculated as weight (kg) divided by height squared (m^2). Resistance (R) measurements were obtained at 50 kHz using a bioelectrical impedance analyzer (Model BIM4, Impedimed, Capalaba, Australia) with a tetrapolar arrangement of self-adhesive electrodes (Red Dot 2330, 3M Healthcare, St Paul, MN, USA). After swabbing the skin on the right hand and foot with alcohol, source electrodes were placed on the dorsal surface of the foot over the distal portion of the second metatarsal, and on the hand on the distal portion of the second metacarpal. Sensing electrodes were placed at the anterior ankle between the tibial and the fibular malleoli, and at the posterior wrist between the styloid processes of the radius and ulna. Testing was initiated after the participants emptied their bladder, and had been lying supine with their arms and legs abducted for at least 10 min. Testing was completed when repeated measurements of R were within 1 Ω of each other. Fat and fat-free mass were calculated from R, height, and weight using a prediction equation previously validated in New Zealand children.[25] %BF was derived as fat mass divided by weight and multiplied by 100. Boys and girls were classified as 'overfat' if their %BF exceeded 25% and 30% (respectively).[28]

Sealed multiday memory pedometers (Model NL-2000, New Lifestyles Inc, Lee's Summit, MO) were used to measure daily steps over three weekdays and two weekend days. An overall mean step count was obtained after scaling the averaged data by a ratio of five weekdays to two weekend days. Recent step count guidelines of 16 000 (boys) and 13 000 (girls) steps per day[30] were used to categorize participants into 'active' and 'inactive' groups. Data were excluded if participants did not wear their pedometer for more than one hour on a given day (as determined by a parent proxy questionnaire). Daily step counts below 1 000 or above 30 000 were regarded as outliers and were removed.[31]

A proxy questionnaire was administered to the parents of each participant to collect information about potential risk factors for obesity while avoiding the recall error associated with self-report surveys in children.[32] Parents were asked how their child usually traveled to and from school, with responses grouped into active (walking, cycling) or motorized transport (car, bus, train). Frequency of breakfast, fast food, and sugary drink consumption in the last full week was determined (servings per week), as were the number of weekdays the participants purchased lunch at school (zero to five days). Participation in organized sport outside of school was assessed for the last full week (zero to seven days). Parents were also asked what time their child usually goes to bed and gets up from bed on weekdays and weekends. The difference between the two times provided the total minutes of sleep for each participant.

Statistical analyses

Data were analyzed using SPSS version 14.0 for Windows (SPSS Inc., Chicago, IL). Differences in participant characteristics (age, height, weight, BMI, and %BF) between sexes and among ethnic groups were assessed by two-way ANOVA, with significant associations examined by pairwise comparisons using *t*-tests. Logistic regression analysis was used to investigate associations between excess body fatness and selected demographic and lifestyle variables. Odds ratios for each category were adjusted for the four demographic factors (sex, age, ethnicity, and SES), and then by all 13 factors concurrently. Ethnic differences in the frequencies of sex, age, and SES categories were examined using the chi-squared test. Analysis of covariance was used to compare the mean %BF between children with and without selected risk factor clusters while adjusting for age, ethnicity, and SES. Differences in the prevalence of overfat were examined using chi-squared analysis. A p value less than 0.05 was used to indicate statistical significance.

RESULTS

The physical characteristics of the three major ethnicities in this study are presented in Table 1. No significant differences in age or height were observed between sexes or among ethnic groups. Polynesian boys and girls were heavier and had higher BMI values than their European and Asian counterparts. European children had less body fat than Polynesian and Asian children of the same sex, although the difference between European and Asian girls was not statistically significant. Boys averaged less body fat than girls across the whole sample and within each ethnic group.

Table 2 shows the unadjusted, partially adjusted (sex, age, ethnicity and SES), and fully adjusted (all factors) odds ratios for excess body fatness for each of the demographic and lifestyle variables assessed. Unadjusted analyses indicated significant associations between fat status and age, ethnicity, SES, physical activity, breakfast, bought lunch, fast food, sugary drinks, and weekday sleep. Adjusting for differences in sex, age, ethnicity, and SES negated associations between fat status and bought lunch, fast food, and sugary drink consumption. However, the partially adjusted odds ratios for three of the four demographic variables remained significant. The odds of overfat increased with age; 11-12-year-old children were 15.4 times more likely to be overfat than those aged 5-6 years. In addition, children from the low SES group were 1.6 and 2.7 times more likely to have excess body fatness than children in the middle and high groups, respectively. While Asian children were 1.8 times more likely to be overfat than European children, differences were not significant for the other two ethnic groups. In the fully adjusted model, bought lunch and sugary drink consumption were restored as significant variables, whereas ethnicity became non-significant.

It is clear that adjusting for demographic differences had a noticeable effect on the odds of overweight between ethnic groups, but not between sex, age, or SES categories. Further analyses revealed no significant variation in sex ($p = 0.539$) or age ($p = 0.561$) distributions among the ethnic groups. In contrast, the SES distribution differed significantly by ethnicity ($p < 0.001$): 73.2% of Polynesian children were in the low SES group and only 8.4% were in the high SES group, compared with 15.8% and 51.0% for European children, and 25.5% and 42.3% for Asian children. To investigate the interaction between SES and ethnicity on fat status, the effects of SES on the odds of overfat were determined for the three major ethnic groups in this study (Fig 1). European and Asian children with a low SES were 2.6 and 3.3 times more likely to be overfat (respectively) than their high SES counterparts (European, $p = 0.006$; Asian, $p = 0.004$). Although Polynesian children in the Low and Middle SES groups were 2.9 and 3.8 times more likely to be overfat (respectively) than those in the High SES group, the difference was significant for the Middle SES group only ($p = 0.044$). There were no significant differences in the odds of overfat between Middle and High SES groups for European ($p = 0.395$) and Asian ($p = 0.430$) ethnicities.

Physical activity, breakfast consumption, and weekday sleep hours were the only lifestyle factors significantly associated with fat status in both the partially and fully adjusted models (Table 2). Children who accumulated less than 16 000 (boys) and 13 000 (girls) steps/day were over two times more likely to be overfat than children who reached these targets. Similarly, children who had breakfast for 3-4 (both models) or 1-2 (partially adjusted model only) days in the preceding week had increased odds of overfat compared with those who had breakfast for five or more days. Of all the lifestyle risk factors, children that sleep for less than 12 hours on weekdays had the highest odds of overfat, rising from 3.4-3.9 in the 11-11.9 hour group to 5.3-7.0 in the < 10 hour group. Active transport, sports participation, and weekend sleep patterns were not associated with fat status either before or after adjustment for the other demographic and lifestyle variables.

The associations between body fatness, overfat prevalence, and various combinations of the lifestyle risk

Table 1. Participant characteristics; results are mean ± SD.†

	European		Polynesian		Asian		All	
	M ($N = 283$)	F ($N = 292$)	M ($N = 201$)	F ($N = 206$)	M ($N = 99$)	F ($N = 97$)	M ($N = 603$)	F ($N = 626$)
Age (yr)	8.2 ± 1.8	8.4 ± 1.7	8.4 ± 1.8	8.4 ± 1.8	8.6 ± 1.7	8.6 ± 1.8	8.4 ± 1.8	8.4 ± 1.8
Height (cm)	131 ± 12.1	131 ± 11.7	133 ± 12.8	133 ± 13.0	131 ± 10.3	130 ± 12.5	132 ± 12.0	131 ± 12.2
Weight (kg)	29.9 ± 8.6‡	30.4 ± 9.7‡	35.3 ± 13.0	35.7 ± 13.9	30.0 ± 8.3‡	29.3 ± 9.2‡	31.7 ± 10.5	31.9 ± 11.4
BMI ($kg{\cdot}m^{-2}$)	17.1 ± 2.4‡	17.3 ± 2.8‡	19.4 ± 4.3	19.5 ± 4.4	17.3 ± 2.8‡	16.9 ± 2.8‡	17.9 ± 3.4	18.0 ± 3.6
Body fat (%)	17.4 ± 6.0§	21.2 ± 6.4‖	20.4 ± 7.5§¶	23.1 ± 7.3	20.1 ± 6.8§¶	23.2 ± 7.5	18.9 ± 6.9§	22.2 ± 6.9

†M, male; F, female; BMI, body mass index. ‡Significantly different from Polynesian of same sex ($p < 0.01$). §Significantly different from female of same ethnic group ($p < 0.01$). ‖Significantly different from Polynesian of same sex ($p < 0.05$). ¶Significantly different from European of same sex ($p < 0.01$).

Table 2. Correlates of overfat (%BF ≥ 25% [boys] or 30% [girls]) in New Zealand children aged 5-11 years.

	Number of Participants (%)		Unadjusted Odds Ratio (95% CI)	Partially Adjusted Odds Ratio (95% CI)†	Fully Adjusted Odds Ratio (95% CI)‡
	Non-overfat	Overfat			
Sex					
Male	500 (48.4%)	103 (52.6%)	1.00	1.00	1.00
Female	533 (51.6%)	93 (47.4%)	0.85 (0.62-1.15)	0.82 (0.59-1.13)	0.85 (0.56-1.27)
Age					
5-6 yr	217 (21.0%)	8 (4.1%)	1.00	1.00	1.00
7-8 yr	375 (36.3%)	37 (18.9%)	2.68 (1.22-5.85)*	2.76 (1.25-6.06)*	3.01 (1.10-8.25)*
9-10 yr	317 (30.7%)	87 (44.4%)	7.44 (3.54-15.7)**	7.84 (3.70-16.6)**	6.32 (2.38-16.8)**
11-12 yr	124 (12.0%)	64 (32.7%)	14.0 (6.50-30.2)**	15.4 (7.07-33.5)**	13.9 (5.06-38.2)**
Ethnicity					
European	514 (49.8%)	61 (31.1%)	1.00	1.00	1.00
Polynesian	318 (30.8%)	89 (45.4%)	2.36 (1.65-3.36)**	1.48 (0.96-2.28)	1.38 (0.81-2.36)
Asian	157 (15.2%)	39 (19.9%)	2.09 (1.35-3.25)**	1.78 (1.12-2.83)*	1.52 (0.86-2.70)
Other	44 (4.3%)	7 (3.6%)	1.34 (0.58-3.11)	0.97 (0.40-2.36)	0.38 (0.11-1.29)
SES					
High	384 (37.2%)	41 (20.9%)	1.00	1.00	1.00
Middle	295 (28.6%)	50 (25.5%)	1.59 (1.02-2.47)*	1.59 (1.00-2.54)*	1.28 (0.74-2.23)
Low	354 (34.3%)	105 (53.6%)	2.78 (1.88-4.10)**	2.73 (1.70-4.38)**	2.09 (1.36-3.20)**
Physical Activity					
Active	431 (51.2%)	51 (30.7%)	1.00	1.00	1.00
Inactive	410 (48.8%)	115 (69.3%)	2.37 (1.66-3.39)**	2.26 (1.54-3.34)**	2.09 (1.36-3.20)**
Active Transport					
None	555 (54.4%)	92 (47.4%)	1.00	1.00	1.00
To or From School	133 (13.0%)	26 (13.4%)	1.18 (0.73-1.90)	1.12 (0.67-1.86)	1.40 (0.78-2.52)
To and From School	333 (32.6%)	76 (39.2%)	1.38 (0.99-1.92)	0.98 (0.69-1.41)	1.12 (0.72-1.75)
Sports Participation					
None	312 (31.0%)	54 (28.0%)	1.00	1.00	1.00
1-2 days/wk	414 (41.1%)	89 (46.1%)	1.24 (0.86-1.80)	1.29 (0.87-1.92)	1.41 (0.88-2.27)
3-4 days/wk	209 (20.7%)	30 (15.5%)	0.83 (0.51-1.34)	0.72 (0.43-1.20)	0.88 (0.48-1.62)
5+ days/wk	73 (7.2%)	20 (10.4%)	1.58 (0.89-2.81)	1.14 (0.62-2.12)	0.91 (0.39-2.11)
Breakfast					
None	13 (1.3%)	5 (2.6%)	2.38 (0.84-6.76)	1.46 (0.47-4.55)	1.38 (0.34-5.56)
1-2 days/wk	43 (4.2%)	20 (10.3%)	2.87 (1.64-5.02)**	1.88 (1.02-3.47)*	1.47 (0.73-2.98)
3-4 days/wk	53 (5.2%)	22 (11.3%)	2.56 (1.51-4.34)**	1.82 (1.02-3.26)*	2.24 (1.08-4.64)*
5+ days/wk	908 (89.3%)	147 (75.8%)	1.00	1.00	1.00
Bought Lunch					
None	603 (59.2%)	107 (55.2%)	1.00	1.00	1.00
1-2 days/wk	341 (33.5%)	65 (33.5%)	1.07 (0.77-1.50)	0.83 (0.58-1.20)	0.69 (0.44-1.08)
3-4 days/wk	33 (3.2%)	13 (6.7%)	2.22 (1.13-4.36)*	1.53 (0.73-3.20)	2.67 (1.03-6.90)*
5+ days/wk	42 (4.1%)	9 (4.6%)	1.21 (0.57-2.55)	0.71 (0.32-1.56)	0.41 (0.15-1.13)
Fast Food					
None	267 (26.3%)	39 (20.1%)	1.00	1.00	1.00
1-2 servings/wk	693 (68.3%)	141 (72.7%)	1.39 (0.95-2.04)	1.42 (0.94-2.15)	1.35 (0.83-2.21)
3-4 servings/wk	47 (4.6%)	9 (4.6%)	1.31 (0.60-2.88)	0.94 (0.41-2.18)	0.67 (0.22-2.07)
5+ servings/wk	7 (0.7%)	5 (2.6%)	4.89 (1.48-16.2)**	3.46 (0.94-12.7)	2.38 (0.48-11.8)
Sugary Drink					
None	159 (15.6%)	22 (11.4%)	1.00	1.00	1.00
1-2 servings/wk	465 (45.5%)	72 (37.3%)	1.12 (0.67-1.86)	1.09 (0.63-1.88)	1.63 (0.80-3.34)
3-4 servings/wk	189 (18.5%)	46 (23.8%)	1.76 (1.02-3.05)*	1.61 (0.90-2.90)	2.26 (1.06-4.84)*
5+ servings/wk	208 (20.4%)	53 (27.5%)	1.84 (1.08-3.16)*	1.56 (0.87-2.79)	2.37 (1.11-5.05)*
Weekday Sleep					
≥ 12 hr	92 (9.2%)	4 (2.2%)	1.00	1.00	1.00
11-11.9 hr	482 (48.1%)	70 (37.6%)	3.34 (1.19-9.38)*	3.36 (1.16-9.76)*	3.92 (1.07-14.4)*
10-10.9 hr	363 (36.2%)	89 (47.8%)	5.64 (2.02-15.8)**	3.96 (1.36-11.5)*	4.23 (1.13-15.8)*
< 10 hr	66 (6.6%)	23 (12.4%)	8.02 (2.65-24.2)**	5.25 (1.62-16.9)**	7.03 (1.63-30.4)**
Weekend Sleep					
≥ 12 hr	138 (14.0%)	20 (11.2%)	1.00	1.00	1.00
11-11.9 hr	362 (36.8%)	50 (28.1%)	0.95 (0.55-1.66)	1.01 (0.56-1.84)	0.70 (0.35-1.43)
10-10.9 hr	358 (36.4%)	78 (43.8%)	1.50 (0.89-2.55)	1.31 (0.74-2.33)	1.02 (0.52-1.99)
< 10 hr	125 (12.7%)	30 (16.9%)	1.66 (0.90-3.06)	1.05 (0.54-2.06)	0.85 (0.38-1.89)

†Adjusted for demographic factors (sex, age, ethnicity, and SES). ‡Adjusted for all other factors. *Significantly different from reference group ($p < 0.05$). **Significantly different from reference group ($p < 0.01$).

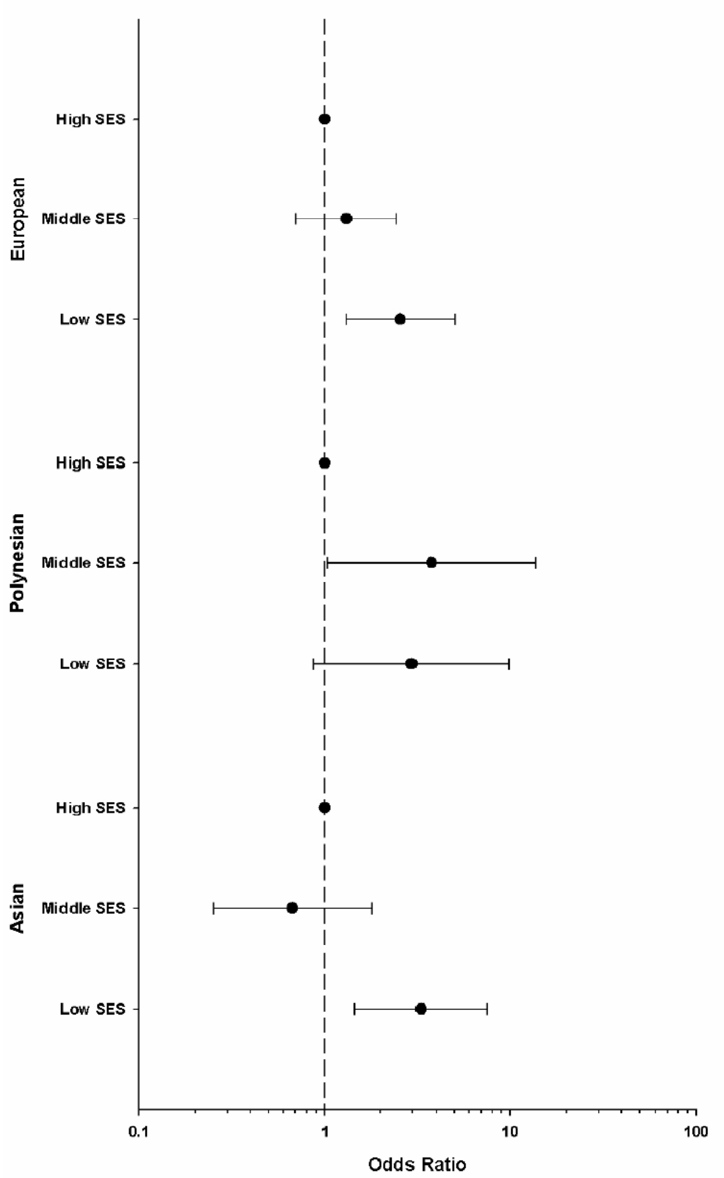

Figure 1. Relationship between the odds of overfat (%BF ≥ 25% [boys] or 30% [girls]) and socioeconomic status in European, Polynesian, and Asian children.

factors identified in all three models (inactivity, skipping breakfast, and low weekday sleep) were assessed separately for boys and girls while adjusting for differences in age, ethnicity, and SES (Table 3). Overall, larger differences in %BF were detected with clusters of two and three risk factors when compared with the single risk factor categories. Although children with lifestyle risk factors showed a greater prevalence of overfat than those without the risk factor(s), not all of the differences between cluster levels were statistically significant. For both boys and girls, chi-squared analysis revealed that the overfat prevalence in the inactive + low breakfast group was significantly higher than in the inactive group (boys, $p = 0.003$; girls, $p = 0.046$), but not in the low breakfast group (boys, $p = 0.286$; girls, $p = 0.266$). Similarly, combining the low breakfast and low weekday sleep groups resulted in a significant increase in overfat when compared with the low weekday sleep group (boys, $p = 0.001$; girls, $p = 0.017$), but not with the low breakfast group (boys, $p = 0.240$; girls, $p = 0.238$). No significant differences were detected between the inactive + low weekday sleep group and each individual risk factor. These findings suggest that skipping breakfast has the greatest effect on the prevalence of excess fatness in this sample. Indeed, the increase in overfat when combining all three risk factors was only significant (boys, $p = 0.004$; girls, $p = 0.042$) when compared to the two-factor cluster that did not already include the low breakfast group (inactive + low weekday sleep).

Table 3. Body fat and prevalence of overfat (**%BF ≥ 25% [boys] and 30% [girls]**) in New Zealand children aged 5-11 years with three key correlates of overfat

Risk Factor(s)	Risk Factor(s) Absent			Risk Factor(s) Present		
	N	Body fat (%)	Overfat (%)	*N*	Body fat (%)	Overfat (%)
Boys						
Inactive (< 16 000 steps/day)	185	17.7 ± 0.9†	11.4	269	20.3 ± 0.8**	23.0**
Low Breakfast (< 5 days)	537	18.6 ± 0.5	14.7	59	21.7 ± 1.7**	37.3**
Low Weekday Sleep (< 11 hours)	297	18.3 ± 0.7	10.8	288	19.5 ± 0.8*	22.1**
Inactive + Low Breakfast	578	18.7 ± 0.5	15.7	24	24.6 ± 2.5**	50.0**
Low Breakfast + Low Weekday Sleep	571	18.7 ± 0.5	15.2	32	23.9 ± 2.2**	50.0**
Inactive + Low Weekday Sleep	466	18.3 ± 0.6	13.3	136	21.3 ± 1.1**	29.9**
Inactive + Low Breakfast + Low Weekday Sleep	588	18.7 ± 0.5	15.8	15	26.5 ± 3.2**	66.7**
Girls						
Inactive (< 13 000 steps/day)	279	21.4 ± 0.8	10.8	236	23.3 ± 0.8**	21.2**
Low Breakfast (< 5 days)	517	21.8 ± 0.6	13.2	97	24.6 ± 1.3**	25.8**
Low Weekday Sleep (< 11 hours)	351	22.3 ± 0.7	12.0	252	22.0 ± 0.9	19.0**
Inactive + Low Breakfast	580	21.9 ± 0.5	13.3	46	25.4 ± 1.9**	34.8**
Low Breakfast + Low Weekday Sleep	587	22.0 ± 0.5	13.5	39	24.4 ± 2.1*	35.9**
Inactive + Low Weekday Sleep	526	22.0 ± 0.6	12.5	100	23.2 ± 1.4	27.0**
Inactive + Low Breakfast + Low Weekday Sleep	606	22.1 ± 0.5	13.7	20	26.0 ± 2.9**	50.0**

†Mean ± 95% CI; adjusted for age, ethnicity, and socioeconomic status. *Significantly different from Risk Factor(s) Absent group ($p < 0.05$). **Significantly different from Risk Factor(s) Absent group ($p < 0.01$).

DISCUSSION

In this study, age, ethnicity, SES, physical activity, breakfast consumption, and weekday sleep duration were identified as important predictors of overfat in New Zealand children. While these findings are generally consistent with earlier research, specific risk factors reported by individual studies vary widely.[11] The discrepancies among studies may reflect fundamental differences between samples, such that observations made in one population may not apply to children from another. Inaccuracies in the techniques used to define childhood obesity may also contribute to the variation. The majority of previous studies have used BMI to estimate fat status. However, the relationship between existing BMI-based definitions of obesity and negative health outcomes in children is not known. Moreover, the use of BMI to classify obesity in multiethnic populations can be problematic.[24,25] The present study used a %BF-based definition of obesity to provide the first description of the correlates of excess fatness in New Zealand children.

Of the four demographic variables assessed in this study, age showed the strongest association with body fat status. This is not surprising given that children tend to accumulate body fat until they reach puberty as part of their normal physiological development.[33] When using a single %BF cut-off point for defining overfat, a natural increase in overfat participants would be expected with age. On the other hand, older children may have been exposed to obesogenic factors for a longer period than younger children. It is also possible that age-related differences in the morbidity associated with body fat could confound the use of a single %BF cut-off point. Although the use of %BF percentiles would account for developmental increases in fat mass by assuming a constant level of %BF for each year of age, there are currently no %BF percentiles related to health outcomes for children. Clearly, more research is needed to establish an internationally applicable definition of excess adiposity for predicting health risk in children of all ages.

The prevalence of excess adiposity was also affected by the deprivation level of the children: those in the low SES group showed greater odds of overfat than those in the high SES group. A variety of explanations have been proposed to explain the relationship between SES and obesity. For example, individuals from lower socioeconomic regions tend to have greater access to unhealthy foods and less knowledge of healthy dietary practices than those from higher socioeconomic regions.[34] Furthermore, physical activity participation in underprivileged communities can be hindered by perceptions of unsafe neighborhoods, limited access to gyms or sports clubs, and higher rates of sedentary activities.[35] While a number of previous studies have shown that socioeconomic factors play a role in the development of childhood obesity,[4-6] their impact may vary across different populations. Wang et al.[6] found that while American children with a low SES were more likely to be overweight than those with a high SES, the inverse relationship was observed in Brazilian children. Although ethnic variation in the relationship between SES and overfat was detected in the present sample, the general trend in all three ethnic groups was similar to that observed in other developed countries.[6]

Our initial analyses showed that Polynesian children were 2.4 times more likely to be overfat than European children. This is consistent with the relatively high prevalence of BMI-determined obesity previously reported in this ethnic grouping.[36,37] After adjusting for sex, age, and SES, differences in fat status between European and Polynesian children were negated. We suggest that the rates of obesity in Polynesian children may have been inflated by their overrepresentation in the 'at-risk' Low SES group. Thus, the traditional view that children of Polynesian descent are predisposed to obesity may largely reflect socioeconomic disadvantages rather than cultural or genetic influences. In contrast, Asian children maintained a significantly higher probability of overfat than European children after adjustment for differences in SES. Whether the increased risk of overfat in Asians is a consequence of fundamental differences in body composition or other sociocultural variables is undecided. However, the exclusion of ethnicity as a significant variable in the fully adjusted model suggests that behavioral factors may be involved.

Several lifestyle-related factors showed significant associations with fat status. In both the partially and fully adjusted models, children who were not sufficiently active were more than twice as likely to be overfat than those who accumulated 16,000 (boys) or 13,000 (girls) steps per day.[30] These findings support the hypothesis that physical activity is inversely related to the risk of obesity in children,[12-15] and highlight the potential advantages of pedometer-based step count targets. Many existing strategies focus on increasing the amount of time children spend on moderate to vigorous activity each day. While beneficial, this approach is less practical and harder to assess than step-based initiatives. This study provides evidence that current step count recommendations are appropriate for reducing the risk of childhood obesity across a range of age, ethnic and SES groups.

Consumption of breakfast less than five days a week was the only dietary practice assessed which increased the odds of overfat in all models. Although several other cross-sectional studies have reported similar results in children and adolescents,[38-41] the mechanisms by which skipping breakfast contributes to the development of obesity remain unclear. Berkey et al.[42] provided evidence that the average number of calories consumed each day is greater in adolescents who regularly eat breakfast than in those who do not, suggesting that skipping breakfast does not promote fat gain through increased energy intake. It is possible that the tendency of overweight youth to skip breakfast is simply due to the high prevalence of dieting practices in this group.[38,43] In this case, reduced breakfast consumption would not be a determinant of obesity, but rather a result of the condition. To our knowledge, no studies have adjusted for differences in dieting behaviors when comparing breakfast patterns between obese and non-obese children.

The final lifestyle factor consistently associated with fat status in this sample was sleep duration on weeknights; children who sleep less than 10 hours each weeknight were over five times more likely to be overfat than those who sleep at least 12 hours. This finding is in line with earlier research suggesting that inadequate sleep is an important predictor of childhood obesity.[4,21-23] However, the mechanisms underlying the association between sleeping patterns and body composition have yet to be elucidated. Interestingly, we found that weekend sleep duration had little effect on the risk of overfat. One hypothesis is that insufficient sleep on weekdays is more strongly related to other obesogenic lifestyle practices than weekend sleep deprivation. Although other studies reported no interactions between sleep duration and other demographic and lifestyle variables,[4,21,22] none compared weekday and weekend sleep patterns. It is also possible that biological mechanisms are responsible for the effects of short sleeping times in children. For example, a lack of sleep is often associated with reduced leptin and elevated ghrelin in adults, two key opposing hormones in appetite regulation.[44,45] Similar hormonal changes in children may result in increased food intake and thus a greater risk of obesity. Nevertheless, this theory does not explain the lack of association between weekend sleep duration and overfat in our sample.

Frequent consumption of fast food, sugary drinks, and lunch bought at school have been reported as dietary risk factors for the development of obesity in children.[16-20] It should be noted, however, that the results presented in previous studies were not adjusted for differences in SES. Controlling for SES (in addition to age, sex, and ethnicity) eliminated the significant associations between fat status and fast food, sugary drinks, and bought lunch in our sample. These findings suggest that the three unhealthy dietary practices are closely related to SES, and may contribute to the elevated risk of overfat observed in underprivileged children.[4-6] Interestingly, the addition of all other lifestyle factors to the model restored the associations between overfat and both sugary drinks and bought lunch. This demonstrates that the relationships between the latter two variables and SES are affected by interactions with other lifestyle practices.

A secondary objective of this study was to investigate the effects of various combinations of lifestyle risk factors on children's body fatness. Knowledge of the risk factor clusters associated with the highest body fat levels would facilitate the development of interventions tailored to those most at-risk. Danielzik et al.[5] showed that combining three demographic risk factors for obesity (low SES, parental overweight, high birth weight) generated the highest risk of overweight in German children. Analyses of the key lifestyle factors in the present study (inactivity, low breakfast consumption, low weekday sleep) indicated similar patterns, with the three-factor combination resulting in a greater mean %BF and prevalence of overfat than the two- or single-factor groups. Although preventative initiatives that target multiple risk factors may offer cumulative benefits, the independent effects of modifiable factors in this study also support interventions that focus on only one risk factor. In our sample, a low frequency of breakfast consumption had the greatest influence on body fatness when compared to the other two lifestyle risk factors.

In summary, we identified several population subgroups at risk for excess fatness in New Zealand; namely older children, Asian children, and those from a low socioeconomic background. While the cross-sectional nature of this study precludes statements of cause-and-effect, our results also demonstrated a clear link between the risk of overfat and daily steps, breakfast consumption, and weekday sleep patterns, regardless of differences in sex, age, ethnicity, or SES. Furthermore, clustering of the major modifiable risk factors was associated with a cumulative increase in adiposity. Longitudinal research is required to determine the effects of these risk factors during development, including the potential implications for adult obesity. Understanding the determinants of excess fatness in young New Zealanders is essential to develop effective strategies for preventing obesity in this population.

ACKNOWLEDGEMENTS

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AUTHOR DISCLOSURES

James Scott Duncan, Grant Schofield, Elizabeth Karndu Duncan and Elaine Caroline Rush, no conflicts of interest.

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Appendix B: Ethics Approval (Chapter 2)

M E M O R A N D U M

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

To: Grant Schofield

From: **Madeline Banda** Executive Secretary, AUTEC

Date: 26 January 2006

Subject: Ethics Application Number 06/04 **Movement in Children Study**

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 on16 January 2006. Your ethics application is now approved for a period of three years until 26 January 2009. 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 a request for extension of the approval if the project will not be completed by the above expiry date;
- 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 «Expiry_Date» or on completion of the project, whichever comes sooner;

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. 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: Scott Duncan scott.duncan@aut.ac.nz

Appendix C: Ethics Approval (Chapter 3)

Student Services Group – Academic Services

AUT

To:	Grant Schofield
From:	**Madeline Banda**
Date:	27 February 2004
Subject:	04/13 Obesity and physical activity in New Zealand primary-aged children

---

Dear Grant

Thank you for providing amendment and clarification of your ethics application as requested by AUTEC.

Your application was approved for a period of two years until 27 February 2006.

You are required to submit the following to AUTEC:

- A brief annual progress report indicating compliance with the ethical approval given.
- A brief statement on the status of the project at the end of the period of approval or on completion of the project, whichever comes sooner.
- A request for renewal of approval if the project has not been completed by the end of the period of approval.

Please note that the Committee grants ethical approval only. If management approval from an institution/organisation is required, it is your responsibility to obtain this.

The Committee wishes you well with your research.

Please include the application number and study title in <u>all</u> correspondence and telephone queries.

Yours sincerely

M Banda.

Madeline Banda
Executive Secretary
AUTEC
CC: 9601299 Scott Duncan

Appendix D: Ethics Approval (Chapters 4-7)

Student Services Group – Academic Services

To:	Grant Schofield
From:	**Madeline Banda**
Date:	5 July 2004
Subject:	04/13 Body composition, physical activity, and dietary patterns in NZ children

Dear Grant

Your application for amendments to your ethics approval was considered by AUTEC at their meeting on 14 June. These amendments were approved by the Committee. Your subsequent request (on 22 June) to change the protocol to remove deception from one of the schools has also been approved.

Your application is approved for a period of two years until 5 July 2006.

You are required to submit the following to AUTEC:

- A brief annual progress report indicating compliance with the ethical approval given.
- A brief statement on the status of the project at the end of the period of approval or on completion of the project, whichever comes sooner.
- A request for renewal of approval if the project has not been completed by the end of the period of approval.

Please note that the Committee grants ethical approval only. If management approval from an institution/organisation is required, it is your responsibility to obtain this.

The Committee wishes you well with your research.

Please include the application number and study title in <u>all</u> correspondence and telephone queries.

Yours sincerely

Madeline Banda
Executive Secretary
AUTEC
CC: 9601299 Scott Duncan

Appendix E: Information Sheet (Chapter 2)

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

MOVEMENT IN CHILDREN STUDY

Primary Researcher: Scott Duncan, MSc(Hons)
Project Director: Grant Schofield, PhD

Dear Sir/Madam,

We are conducting a study looking at physical activity in New Zealand primary-aged children. Your child is one of 190 children randomly selected as a possible participant from _________ School. Around half will eventually take part in the study. Please read this form and ask any questions you may have before signing the statement of consent. Please note that your child will only be part of the study if he/she is randomly selected as one of the final participants. Your child is also required to read his/her information sheet and sign the green consent form before he/she can participate (younger children may need assistance).

Background Information

An increasing number of New Zealand children and adolescents are suffering from overweight and obesity. Because of this, AUT has invested in a series of studies that will focus on preventing this problem in younger children before it develops. Information from the current study will help us to understand how much energy children expend at various movement speeds. It also forms part of a larger PhD study that will validate the use of pedometers to measure steps in children.

The main purposes of this study are:

- To understand how fast children normally move during lunch time.
- To see if pedometers are accurate at measuring steps in children when moving at different speeds.
- To see if body proportions (e.g. height, weight, amount of fat tissue) are related to the amount of energy children expend or the speed at which they normally move.
- To provide you with an individualised report on the body composition of your child.

Procedures

1. If you allow your child to be in this study, we will measure the speed at which he/she moves during one lunch time using a GPS unit that is worn in a child-size shoulder pouch. The GPS unit uses satellites to work out how fast your child is moving while he/she plays. It is completely safe, and will be comfortable to wear.

2. Your child's heart rate will be recorded over lunch time using a heart rate monitor. Once again, this device is completely safe and will be easy for him/her to play in. This tells us how much energy your child is using during walking and running.

3. A few days after we have tested your child's speed and energy, we will bring a treadmill to the school and ask him/her to walk at various speeds while we count steps. Your child will also be wearing two step-counting pedometers so we can test how accurate they are.

Your child will not be on the treadmill for more than 15 minutes, and we will have breaks in between so he/she does not get tired.

4. We will measure your child's height, waist size and hip size using a tape measure, and his/her weight using scales. Your child will be asked to remove his/her shoes and any heavy outer clothing for these measurements.

5. We will estimate the percentage of body fat your child has by using a technique called bioelectrical impedance analysis. This will require your child to lie down for about five minutes in the testing room while a torch battery powered meter measures the amount of body fat he/she has. This technique is completely safe, painless, and has been used many times to estimate body fat in children.

The lunch time tests will be conducted at __________ School between __________ and _________ (two children each day). The body composition testing will take approximately 15 minutes to complete for each child, and will be done before the treadmill testing on _________. You are more than welcome to attend this testing period. Please note that your child may be selected for the body composition testing without completing the GPS testing (depending on availability of equipment). An individualised report will be prepared that lists all of the body composition information we collected from your child.

Confidentiality

The records of this study will be kept private. However, you will be given access to any information we collect about your child. In any sort of report we publish, we will not include information that will make it possible to identify you or your child in any way. Research records will be kept in a locked file; Dr Schofield and Mr Duncan are the only people who will have access to the records. Data may be used for comparative purposes in future studies, however all data will be stored by participant code to ensure confidentiality.

Voluntary Nature of the Study

Your child's participation in this study is entirely voluntary. Whether or not you allow your child to participate will not affect his/her or your own current or future relations with ________ School or AUT. If you decide to allow participation, you are free to withdraw your child from the study at any time without penalty. Should you decide to withdraw your child from the study, any data we may already have collected will not be used without your consent. If your child does not wish to participate before or during testing, or shows any sign of distress, we will immediately discontinue his/her assessment.

Contacts

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Grant Schofield, grant.schofield@aut.ac.nz, 921 9999 ext 7037.

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.

This study was approved by the Auckland University of Technology Ethics Committee on _______, AUTEC Reference Number _______.

Appendix F: Information Sheet (Chapter 3)

AUCKLAND UNIVERSITY OF TECHNOLOGY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

PHYSICAL ACTIVITY IN NEW ZEALAND PRIMARY-AGED CHILDREN

Primary Researchers: Scott Duncan, Amy Flower
Project Supervisor: Dr Grant Schofield

Dear Sir/Madam,

We are conducting a large-scale study about physical activity in New Zealand primary-aged children. Your child is one of 88 children randomly selected as a possible participant from his/her school. Forty-four children will eventually be asked to take part in the study. Please read this form and ask any questions you may have before signing the statement of consent. Please note that your child will only be part of the study if he/she is randomly selected as one of the final 44 participants.

Background Information

An increasing number of New Zealand children and adolescents are suffering from overweight and obesity. Because of this, AUT has invested in a series of studies that will focus on preventing this problem in younger children before it develops. Information from the current study will help us to understand the best way to do this in New Zealand children. It also forms part of a larger PhD study.

The main purposes of this study are:

- To understand how much physical activity New Zealand children do during a normal day.
- To provide you with an individualised report on the activity level of your child.

Procedures

If you allow your child to be in this study, we will measure the number of steps he/she takes each day by using a step-counting device called a pedometer. Pedometers are about the size of a matchbox and are completely safe. We would ask you to attach the pedometers at your child's waist level (in line with the front of the right thigh) as soon as he/she gets up each day, and remove it when he/she is sleeping, showering, or swimming (pedometers are not waterproof). We will give the pedometers to your child on Monday, July 26, and will collect them on Friday, July 30. This will tell us how many steps he/she has achieved for each of the five previous days. We will provide you with a report of this information. It is very important that your child continues his/her normal routine during the five days, and because of this we will ask that you **do not** discuss the study nor the purpose of the pedometer (i.e., to count steps) with him/her until after we have collected them.

Confidentiality

The records of this study will be kept private. However, you will be given access to any information we collect about your child. In any sort of report we publish, we will not include information that will make it possible to identify you or your child in any way. Research records will be kept in a locked file; Dr Schofield, Mr Duncan, and Ms Flower are the only people who will have access to the records.

Voluntary Nature of the Study

Your child's participation in this study is entirely voluntary. Whether or not you allow your child to participate will not affect his/her or your own current or future relations with his/her school or AUT. If you decide to allow participation, you are free to withdraw your child from the study at any time without penalty. Should you decide to withdraw your child from the study, any data we may already have will not be used without your consent. If your child does not wish to participate before or during testing, or shows any sign of distress, we will immediately discontinue his/her assessment.

Contacts and Questions

Please feel free to contact us anytime to ask questions or voice concerns about the study.

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Fax: 09-917-9960
E-mail: grant.schofield@aut.ac.nz

Concerns regarding the conduct of the study should be directed to:

Madeline Banda
Executive Secretary
AUT Ethics Committee
Ph: 09-917-9999 ext 8044
Fax: 09-917-9812
E-mail: madeline.banda@aut.ac.nz

Appendix G: Information Sheet (Chapters 4-7)

AUCKLAND UNIVERSITY OF TECHNOLOGY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

PHYSICAL ACTIVITY AND BODY COMPOSITION IN NEW ZEALAND PRIMARY-AGED CHILDREN

Primary Researcher: Scott Duncan, MSc(Hons)
Project Director: Grant Schofield, PhD

Dear Sir/Madam,

We are conducting a large-scale study looking at physical activity and body composition in New Zealand primary-aged children. Your child is one of 100 children randomly selected as a possible participant from ____________ School. Forty-four children will eventually take part in the study. Please read this form and ask any questions you may have before signing the statement of consent. Please note that your child will only be part of the study if he or she is randomly selected as one of the final 44 participants.

Background Information

An increasing number of New Zealand children and adolescents are suffering from overweight and obesity. Because of this, AUT has invested in a series of studies that will focus on preventing this problem in younger children before it develops. Information from the current study will help us to understand the best way to do this in New Zealand children. It also forms part of a larger PhD study.

The main purposes of this study are:

- To understand how much physical activity New Zealand children do during a normal day.
- To see if body proportions (e.g. height, weight, amount of fat tissue) are related to the amount of activity children do each day.
- To provide you with an individualised report on the activity level and body composition of your child.

Procedures

1. If you allow your child to be in this study, we will measure the number of steps he/she takes each day by using a step-counting device called a pedometer. Pedometers are about the size of a matchbox and are completely safe. We would ask you to attach the pedometers at your child's waist level (in line with the front of the right thigh) as soon as he/she gets up each day, and remove it when he/she is sleeping, showering, or swimming (pedometers are not waterproof). We will give the pedometers to your child on ____________, and will collect them on ____________. This will tell us how many steps your child has achieved for each of the five previous days. A full report of this information will be provided. It is very important that your child continues her normal routine during the five days, and because of this we will ask that you <u>do not</u> encourage him/her to be active more than you normally would. Also, please make sure the cable tie is not removed from around the pedometer.

2. We will measure your child's height, waist size and hip size using a tape measure, and his/her weight using scales. Your child will be asked to remove his/her shoes and any heavy outer clothing for these measurements.

3. We will estimate the percentage of body fat your child has by using a technique called bioelectrical impedance analysis. This will require your child to lie down for about five minutes in the testing room while a torch battery powered meter measures the amount of body fat he/she has. This technique is completely safe, painless, and has been used many times to estimate body fat in children.

All tests will be conducted at ____________ School on the morning of ____________, and will take approximately 15 minutes to complete for each child. You are more than welcome to attend this testing period. An individualised report will be prepared that lists all of the information we collected from your child.

Confidentiality

The records of this study will be kept private. However, you will be given access to any information we collect about your child. In any sort of report we publish, we will not include information that will make it possible to identify you or your child in any way. Research records will be kept in a locked file; Dr Schofield and Mr Duncan are the only people who will have access to the records.

Voluntary Nature of the Study

Your child's participation in this study is entirely voluntary. Whether or not you allow your child to participate will not affect his/her or your own current or future relations with Riverina School or AUT. If you decide to allow participation, you are free to withdraw your child from the study at any time without penalty. Should you decide to withdraw your child from the study, any data we may already have collected will not be used without your consent. If your child does not wish to participate before or during testing, or shows any sign of distress, we will immediately discontinue his/her assessment.

Contacts and Questions

Please feel free to contact us anytime to ask questions or voice concerns about the study.

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This study was approved by the Auckland University of Technology Ethics Committee on 05/07/04, AUTEC Reference Number 04/13. AUTEC contact: Madeline Banda, Executive Secretary, AUTEC, Ph: 09-917-9999 ext 8044, Fax: 09-917-9812, e-mail: madeline.banda@aut.ac.nz.

Appendix H: Consent Form (Chapters 2-7)

AUCKLAND UNIVERSITY OF TECHNOLOGY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Primary Researcher: Scott Duncan, MSc(Hons)
Project Director: Grant Schofield, PhD

Statement of Consent

- I have read and understood the information provided about this research project.
- I have had the opportunity to ask questions and to have them answered.
- I understand that I may withdraw my child or any information that my child or I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- I give consent for my child to participate in the study.
- I give consent for the confidential information provided in the questionnaire to be used by AUT for research purposes.

____
Name of Child

___________________________________ ___________________________________
Signature of Child Date

____
Name of Parent or Caregiver

___________________________________ ___________________________________
Signature of Parent or Caregiver Date

If you consent, please place the signed consent form (green) with the completed questionnaire form (blue) in the envelope provided and ask your child to give it to his or her teacher by _______________.

Appendix I: Pedometer Compliance Questionnaire (Chapters 3-7)

AUCKLAND UNIVERSITY OF TECHNOLOGY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Primary Researcher: Scott Duncan, MSc(Hons)
Project Director: Grant Schofield, PhD

Dear Sir/Madam,

Thank you once again for allowing your child to participate in this study. Please make sure he/she is wearing the pedometer tomorrow morning so that we can collect the physical activity information before the pedometer resets.

We would also like to know how often your child wore the pedometer over the testing period. When your child goes to bed on tonight, please fill in the details in the box below and ask your child to return the form to the teacher tomorrow morning in the envelope provided.

Many thanks,

AUT Research Team

How many hours of the following days was your child **not** wearing the pedometer (not including sleep time)? If it was worn all the time, please write 'nil'.

Wednesday, December 8______________________________

Thursday, December 9 ______________________________

Friday, December 10 ______________________________

Saturday, December 11______________________________

Sunday, December 12 ______________________________

Appendix J: Parent Questionnaire (Chapter 7)

AUCKLAND UNIVERSITY OF TECHNOLOGY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

QUESTIONNAIRE FOR PARENTS/CAREGIVERS

This brief questionnaire will help us understand more about your child's activity and body composition. All answers will be kept completely confidential. When completed, please place this blue questionnaire form with the signed green consent form in the envelope provided and ask your child to give it to his or her teacher tomorrow.

Thank you.

1. What is your child's birth date?

______/______/______

2. What was your child's birth weight?

____

3. If your child has any other young people (less than 20) living with them, please list their age and relationship to your child:

e.g. *Brother, 15 years*

____
____
____
____
____
____

4. How many rooms in your household have a television?

- None ☐
- 1 ☐
- 2 ☐
- 3 ☐
- 4 or more ☐

5. Does your child have a television in his or her room?

- Yes ☐
- No ☐

6. Does your child have access to a games console (e.g., Playstation, Xbox etc) in your household?

- Yes ☐
- No ☐

7. Does your child have access to a personal computer in your household?

- Yes ☐
- No ☐

8. How often do you restrict the amount of time your child spends on the following activities:

	Never	Sometimes	Often	N/A
Television	☐	☐	☐	☐
Games Console	☐	☐	☐	☐
Computer	☐	☐	☐	☐

9. How often does your child spend time on homework?

- Never ☐
- Some nights ☐
- Most nights ☐
- Every night ☐

↓ **please turn over** ↓

10. How does your child usually travel **<u>to</u>** school? (tick one)

- Car □
- Bus □
- Bicycle □
- Walk □
- Other ____________________

11. How does your child usually travel **<u>from</u>** school? (tick one)

- Car □
- Bus □
- Bicycle □
- Walk □
- Other ____________________

12. How many days each week does your child play or practise organised sport outside of class hours?

- None □
- 1-2 □
- 3-4 □
- 5 or more □

13. How many days did your child eat breakfast in the last full week (Mon → Sun)?

- None □
- 1-2 days □
- 3-4 days □
- 5-6 days □
- Everyday □

14. How many days did your child buy lunch at school in the last school week (Mon → Fri)?

- None □
- 1-2 days □
- 3-4 days □
- Everyday □

15. How many times did your child eat takeaways or fast food in the last full week (Mon → Sun)?

- Never □
- 1-2 □
- 3-4 □
- 5-6 □
- 7 or more □

16. How many times did your child have a sugary drink (e.g., Coca-Cola, cordial) in the last full week (Mon → Sun)?

- Never □
- 1-2 □
- 3-4 □
- 5-6 □
- 7 or more □

17. What time does your child normally:

- Go to bed on a weekday? _________
- Get up on a weekday? _________
- Go to bed on Saturday? _________
- Get up on Sunday? _________

18. How many parents/caregivers regularly live with your child? _________

19. Do you consider your child to be:

- Underweight □
- Normal weight □
- Overweight □

20. Do you consider your child's activity levels to be:

- Below average □
- Average □
- Above average □

21. Do you consider your child's eating patterns to be:

- Healthy some of the time □
- Healthy most of the time □
- Healthy all of the time □

Appendix K: Feedback Form (Chapters 4-7)

AUCKLAND UNIVERSITY OF TECHNOLOGY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

PHYSICAL ACTIVITY AND BODY COMPOSITION IN NEW ZEALAND PRIMARY-AGED CHILDREN

Primary Researcher: Scott Duncan, MSc(Hons)
Project Director: Grant Schofield, PhD

Feedback Form

This form summarises the information we have collected about your child. We have also summarised data from the other children we measured from _______ School. The Frequently Asked Questions on the other side of this page may help if you are unsure of what this information means.

Physical Activity

Wednesday	_______	steps
Thursday	_______	steps
Friday	_______	steps
Saturday	_______	steps
Sunday	_______	steps
Average	_______	steps/day

Body Composition

Weight	____	kg
Height	____	m
BMI	____	kg/m^2
%BF	____	%

Body Fat Distribution

Waist Size	____	cm
Hip Size	____	cm
WHR	____	

School Averages

	Boys	Girls
Steps/day	_____	_____
BMI	_____	_____
%BF	_____	_____
WHR	_____	_____

We hope you have found the information presented in this feedback form interesting. Please pass on our thanks to your child for contributing to our knowledge of physical activity and body composition in New Zealand children.

Many thanks,

AUT Research Team

Frequently Asked Questions

Q: How many steps should my child be doing each day?
A: At present, there is very little information about the number of steps children need to do each day to obtain health benefits. In adults, 10,000 steps per day appears to be a good target to improve health and lose excess weight. However, children require a higher level of activity than adults. Overseas studies show that children tend to achieve about 12,000 to 15,000 steps per day, with boys more active than girls. This study will provide the first step count information for New Zealand children.

Q: What does BMI mean?
A: BMI stands for Body Mass Index. It is a measure of how much weight your child has when taking their height into account. BMI is used around the world to describe body size. However, it is considered most useful when looking at populations, not individuals. If your child has a high BMI, it does not necessarily mean that they are overweight. For example, Pacific Island and Maori children tend to have more muscle and larger bones than other ethnic groups, and may be misclassified using BMI. This is the reason we also measured the percentage body fat of your child (see next question).

Q: What does %BF mean?
A: Percentage body fat (%BF) refers to the amount of fat your child has compared with other body tissue, such as muscle and bone. Children generally gain more fat as they age, with girls tending to have higher %BF than boys. Studies have suggested that a %BF greater than 25% for boys and 30% for girls can be unhealthy. The best way to ensure that your child maintains a healthy %BF is to encourage them to be physically active and to make sure that they eat a wide range of food with lots of fruit and vegetables.

Q: What does WHR mean?
A: WHR stands for waist-to-hip ratio (waist size divided by hip size). A higher WHR means that fat tends to gather around the stomach (common in men), whereas a lower WHR means that fat tends to gather around the hips and bottom (common in women). Risk of health problems in both children and adults generally increases as WHR becomes higher (i.e., nearer to 1.00), as it means more fat is located around the heart. However, specific WHR values that are healthy for New Zealand children are not yet known.

Q: Whom can I contact if I am worried about my child's health status?
A: The best person to advise you about your child's health is your local doctor.

Q: Whom can I contact for more information about physical activity and nutrition in children?
A: Some good sources of information include: Sport and Recreation New Zealand (www.sparc.org.nz), the Ministry of Health (www.moh.govt.nz), the National Heart Foundation (www.heartfoundation.org.nz), and the Nutrition Society of New Zealand (www.nutritionsociety.ac.nz).

Appendix L: Distribution of Participating Schools (Chapters 4-7)