Physical Activity in New Zealand Preschoolers: Amount, Associations, and Accounts

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List of Abbreviations

Abbreviation	Definition
AEE	Activity-related energy expenditure
BEACHES	Behaviors of Eating and Activity for Child Health: Evaluation System
BMI	Body mass index
CARS	Children's Activity Rating Scale
CAT	Children's Activity Timesampling Method of Observation
CPAF	Children's Physical Activity Form
ECE	Early childhood education
EE	Energy expenditure
FATS	Fargo Activity Timesampling Survey
GEE	Generalised estimating equation
HEHA	Healthy Eating-Healthy Action
LPA	Light physical activity
MPA	Moderate physical activity
MVPA	Moderate-to-vigorous physical activity
n	Sample size
NPAQ	Netherlands Physical Activity Questionnaire
NZ	New Zealand
OSRAC-P	Observational System for Recording Physical Activity in Children-Preschool Version
PA	Physical activity
REE	Resting energy expenditure
RMA	Resource Management Act 1991
SCAN	Study of Children's Activity and Nutrition
SPARC	Sport and Recreation New Zealand
TEE	Total energy expenditure
TV	Television
US	United States of America
VO_2	Oxygen consumption
VO_{2max}	Maximum oxygen consumption
VPA	Vigorous physical activity
WC	Waist circumference

Nomenclature

Term/symbol	Definition
α	alpha
CI	confidence interval
cm	centimetre
κ	Cohen's kappa statistic
kg	kilogram
m	metre
$mL \cdot kg^{-1}$	millilitre per kg
$mL \cdot kg^{-1} \cdot min^{-1}$	millilitre per kg per minute
$m.s^{-1}$	metres per second
P	P-value
Φ	phi coefficient
r	correlation coefficient

List of Publications Arising from Doctoral Thesis

Peer-reviewed Journal Publications

Papers in submission

1. <u>Oliver, M.</u>, Schluter, P. J., & Schofield, G. M. (in submission). Objectively assessed physical activity in preschoolers and their parents. *Journal of Science and Medicine in Sport.*

Papers published

2. <u>Oliver, M.</u>, Schofield, G. M., & Schluter, P. J. (in press). Utility of accelerometer thresholds to classify physical activity in preschoolers. *Measurement in Physical Education and Exercise Science.*
3. <u>Oliver, M.</u>, Schofield, G. M., & Kolt, G. S. (2007). Physical activity in preschoolers: Understanding prevalence and measurement issues. *Sports Medicine, 37*(12), 1045-1070*.*
4. <u>Oliver, M.,</u> Schofield, G. M., Kolt, G. S., & McLachlan, C. (2007). Physical activity in early childhood: Current state of knowledge. *NZ Research in Early Childhood Education, 10,* 47-68*.*
5. <u>Oliver, M.</u>, Schofield, G. M., Kolt, G. S., & Schluter, P. J. (2007). Pedometer accuracy in physical activity assessment of preschool children. *Journal of Science and Medicine in Sport, 10*(5), 303-310.
6. <u>Oliver, M.</u>, & McLachlan, C. M. (2007). Physical activity. An overview of policy and practice in early childhood education and care. *Early Education, 40,* 15-19*.*

Peer-reviewed Conference Presentations and Associated Publications

Papers published/in press

7. Oliver, M., Schofield, G. M., & Schluter, P. J. (2008). Accelerometer-determined physical activity in preschoolers and their parents. *Poster presented at the 10th International Congress of Behavioral Medicine,* Tokyo, Japan, 27-30 August 2008.

8. Oliver, M., Schluter, P. J., & Schofield, G. M. (2008). Utility of motion sensors to classify physical activity in pre-schoolers. *Paper presented at the International Society of Behavioral Nutrition and Physical Activity 2008 Meeting*, Banff, Alberta, Canada, 21-24 May 2008.

9. Oliver, M., Schofield, G. M., Kolt, G. S., & Schluter, P. J. (2006). Pedometer and accelerometer accuracy in physical activity assessment of preschool children. In *NZ Satellite Meeting of the International Congress of Obesity Handbook* (pp. 21-22). Auckland, NZ: Australasian Society for the Study of Obesity.

10. Oliver, M., Schofield, G. M., Kolt, G. S., & Schluter, P. J. (2006). Pedometer and accelerometer accuracy in physical activity assessment of preschool children [Abstract]. *Medicine & Science in Sports & Exercise, 38*(Suppl. 5), S565.

11. Oliver, M.*,* & McLachlan, C. M. (2006). How fit are our children? An examination of physical activity in the ECE curriculum. *Paper presented at the AUT Curriculum Forum*, Auckland, NZ: AUT University.

Non Peer-reviewed Publications

Papers published

12. Oliver, M., Schluter, P. J., & Schofield, G. M. (2008). Factors related to physical activity in preschool-aged children. Paper presented at HEHA Research, Evaluation and Monitoring Conference: 'What's happening in our back yard?', Wellington, NZ: Ministry of Health.

13. Oliver, M. (2006). Physical activity in early childhood education. Issues and challenges. *Swings & Roundabouts, 2,* 18-19.

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.

Chapters 2-6 have been submitted for consideration as separate papers for publication in international peer-reviewed journals. Each of these papers was conceived by the candidate, who was also the main contributor and author. All co-authors have approved the inclusion of the papers they were involved in as chapters for this thesis. Individual contributions for these chapters are outlined in the introduction (Chapter 1).

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10 November 2008

Acknowledgements

Thesis Abstract

Improving physical activity (PA) participation is a public health priority in developed and developing countries to curb the substantial and growing prevalence of lifestyle-related diseases. Early childhood may be an especially important time to encourage PA; however, there is a paucity of research in this area.

The aim of this research was to contribute to the limited body of work in PA in early childhood by investigating PA measurement approaches in young children and applying this knowledge to determine socio-environmental associations of preschool PA. An initial literature review provided the background for the thesis and determined the approaches taken in the ensuing chapters. A second literature review provided a detailed critique of research specific to PA measurement in early childhood to further inform the empirical studies. Information for the empirical chapters was drawn from three research projects: two studies were completed that assessed tools for objectively measuring PA in young children (pedometers and accelerometers), and these studies informed a final project to quantify associates of PA in a sample of preschool-aged children.

Novel and important findings from the preliminary studies were that pedometer accuracy for measuring free-living PA and walking in children aged 3-5 years was poor, especially for pedometers worn at the back of the child, or during slow walking. Furthermore, when investigating the utility of accelerometers (more complex and frequently adopted tools) to quantify PA intensity in preschoolers, their application and use of commonly employed thresholds resulted in systematic underestimation of PA intensity and poor agreement (κ=0.09) when compared with a direct observation criterion measure. Application of existing accelerometer thresholds to classify PA intensity in preschoolers was therefore likely to yield biased estimates.

Given the dearth of robust alternatives, a novel approach was developed to calculate individual activity rates from the raw accelerometer data. To account for over-dispersion in accelerometer counts, daily average activity rates per second were derived for each participant using negative binomial generalised estimating equation (GEE) models with a first-order autoregressive (AR1) correlation structure. These rates were assumed to be exchangeable between days and normally distributed. Potential socio-environmental associates of children's activity rates and body size were thus assessed using normal GEE models with exchangeable correlation structures. Parental PA and child age were independently and significantly associated with child activity rates ($P \leq 0.04$). No relationships between child body size and PA or television (TV) exposure were found.

Common approaches to PA measurement and data consideration were challenged in this research and novel robust methods devised utilising contemporary statistical methods. Accelerometer data can be successfully reduced to individual activity rates to mitigate current issues related to objective PA quantification with preschoolers. Parental involvement in preschool PA interventions is worthy of further investigation, and younger children may stand to benefit more from increased activity. Further exploration of the complex interactions between PA, exposure to media, and health outcomes in preschool-aged children is warranted.

Chapter 1: Introduction

Background

Context

The positive role of regular PA in adult health and wellbeing is well documented, including a reduced risk of developing cardiovascular disease, overweight or obesity, type 2 diabetes, colon cancer, breast cancer, osteoporosis, and depression.[1,2] Conversely, physical inactivity is second only to cigarette smoking in terms of modifiable risk factors and their direct attributable burden of disease,[2] conservatively estimated to annually cause 2,000 (or 8%) of New Zealand (NZ) deaths, and 1.9 million deaths worldwide.[3] More recently, PA researchers have begun to shift their focus to exploring these relationships in population sub-samples, including adolescents and children. Similar benefits have been observed, with regular PA in school-aged children and adolescents shown to confer improved bone health,[4] blood pressure and lipid profiles,[5] and a reduced likelihood of developing type 2 diabetes[6] and being obese or overweight.[7-9]

Overweight and obese school-aged children are more likely to develop risk factors for cardiovascular disease and diabetes,[10] and are at substantially greater risk of developing adult obesity.[11] PA during the school years may predict activity in later life;[12-16] conversely, inactivity may track into adulthood.[17] A pattern of reduced activity participation when children reach adolescence has been observed,[18-21] and a trend of decreased PA has been measured in NZ youth aged 5-17 years.[19] Of particular concern, the NZ National Children's Nutrition Survey showed that children as young as 5 years of age are already entering primary school overweight and inactive,[22] indicating that PA promotion and obesity prevention in the preschool years ($\leq$5 years) may be beneficial. PA in preschool-aged children, however, has been relatively under-studied compared to their older peers, and there is a paucity of published information related to PA in the early childhood years.

Nearly all NZ children aged 3-4 years, and two-thirds of 2 year old NZ children attended some form of Early Childhood Education (ECE) or care in 2007,[23] making these settings important contexts for PA promotion efforts. Approximately 44% of centres are private, with the remainder being a mixture of community playcentres and kindergartens, kōhanga reo, Pacific Islands language nests, and playcentres. The NZ Education (Early Childhood Centre) Regulations[24] require that all new and existing centres must allow for outdoor hard play areas of between 2-5 m^2 per child. In the context of this thesis, the terms 'young child', 'early child', 'preschool', and their extensions refer to children aged ≤ 5 years, and are used interchangeably throughout.

Activity and Health in the Preschool Years

At the time of commencing this thesis, there was sufficient evidence to show a positive relationship between PA and improved bone health,[25,26] motor skill development,[27] and a reduced risk of being overweight or obese.[28,29] Conversely, inactivity, often classified using TV watching time, had been consistently linked with body size in young children.[28,30-35] United States of America (US) data have shown a 26.4% increase in prevalence of overweight children aged 2 to 6 years from 1992 to 2001;[36,37] obesity prevalence in US preschoolers increased from 6.3% to 10.0% from 1980 to 2001, and overweight prevalence grew from 11.1% to 14.4%.[38] NZ is no exception to this problem, with nearly one third of NZ school-aged children overweight or obese.[22] While no prevalence data exists for NZ preschool children, a cohort study in Dunedin, NZ reported over a quarter of the 3 year olds sampled were overweight or obese at baseline.[39] The prevalence of PA and inactivity, and dose-response relationships between these factors and health outcomes in young children is not well understood. Whether PA behaviours are reducing concomitantly with increasing obesity prevalence is yet to be determined. Even so, considering that weight status tracks from infancy to early childhood to late childhood,[40,41] PA during childhood is likely to predict later activity,[12-17] and the preschool years are undoubtedly an important life-stage to consider the importance of PA. Given the current dearth of robust research in this area, it is imperative that quality research to improve our knowledge and understanding of PA in the early childhood years is considered a priority area for researchers internationally.

The Wider Environment

Research with older populations indicate that changing activity profiles (i.e., decreased PA, increased inactivity) are fundamental to the epidemic levels of obesity, type 2 diabetes, and associated co-morbidities.[42] Environmental changes are key to explaining this shift in behaviour – the modern climate in developed countries is one of time-saving (and thus reducing energy requirements) technologies predominantly in the form of cars, remote controls, and household appliances.[43] Although current evidence is ambiguous, it is possible that inactivity-reinforcing devices such as TV, games consoles, computers, and the internet may also compete with leisure time activity. Contemporary built environments are frequently constructed to facilitate motorised transport and provide little opportunity for community-level PA. Young children are not immune to these culture and technological shifts, and it is likely that their activity patterns have altered in response to these changes.

A multilevel approach[44] to investigating influencing factors on preschoolers' PA is needed. Identification of individual, familial, community, and wider ecological associates of activity in preschoolers will enable researchers to understand how best to encourage increased PA and reduced inactivity in young children. PA intervention in early childhood is recommended by the American Heart Association; one of their key strategies to achieve this for toddlers was through "increasing daily PA (e.g., active play 1h/d), and limiting sedentary time (e.g., watching TV $\leq$2 h/d)."[45] Even so, while the importance of PA promotion (and inactivity reduction) within families, schools, and communities in preschool years is well acknowledged,[46,47] PA interventions with preschoolers have been scarcely reported in the literature. Prior to investigating the efficacy of interventions, it is essential to develop robust PA measurement methods to facilitate epidemiological quantification of PA and health outcomes in preschool-aged children.[48] Objective PA measures (e.g., pedometers, accelerometers) are ideal for epidemiological purposes, as these eliminate potential inaccuracies resulting from subjective bias (e.g., self-report, proxy-report, researcher coding bias).[49,50]

Statement of the Problem

Current knowledge posits that increased PA in early childhood confers a multitude of health benefits, while inactivity is associated with increased health risk. PA prevalence in preschoolers is unknown, however, it is likely that current levels are insufficient to curb the growing obesity epidemic in this population.[36-38] To date, efficacious interventions remain wanting. Determining and understanding the complex relationships between PA, body size, and inactivity, and the social and environmental factors associated with PA in young children is vital for the development of successful PA interventions and therefore improved long-term health outcomes. Intuitively the immediate family is of importance as the young child's attitudes, beliefs, and behaviours are moulded within this unit. Preschool children have almost complete reliance on older children and adults (e.g., siblings, parents) for PA opportunities. Parental PA levels[51] and parental encouragement of PA in their preschool-aged child[52] have been linked with objectively measured activity; however these relationships are yet to be convincingly determined using robust and consistent objective PA measurement methods. Commencing this thesis, the greatest barrier to understanding relationships between PA and potential associates and health outcomes in preschool-aged children was the absence of a best practice approach for objectively quantifying preschoolers' PA.

Although widely successfully implemented with older children and adults, pedometer use with preschoolers had been scarcely reported or critiqued. Accelerometers were the objective measurement tool most commonly employed with preschool populations, yet no consensus existed for appropriate treatment of accelerometer data. Central to this problem was the common use of accelerometer count thresholds to define activity intensity, an approach which is problematic with preschoolers for three key reasons: (i) activity types and durations used for threshold calibration are often not representative of young children's usual behaviours, which may result in misclassification of activity intensity; (ii) epoch durations of commonly used accelerometers may not be adequately short to capture the sporadic behaviours characteristic of young children; and (iii) a blanket approach to classifying PA intensity fails to deal with the substantial developmental differences and movement patterns between

individuals in this age group.[53-55] To date, a variety of approaches to accelerometer data treatment have been undertaken by researchers, resulting in inconsistent reporting of activity levels, and a general lack of understanding of activity prevalence, patterns, and associates in this population.

Statement of Purpose

The overall aim of this research was to contribute to the limited body of work in PA in early childhood by investigating best practice approaches to quantifying PA in young children and applying this knowledge to determine socio-environmental associations of PA in a preschool-aged population. Specific objectives (and related chapters) were to:

1. Review and critique existing literature related to PA associates and measurement in preschool-aged children (Chapters 2-3).
2. Develop an accurate, robust method for PA quantification in preschoolers for application in future research by taking the following approaches:
   a. Determine the utility of Yamax SW-200 Digiwalker pedometers for use with children aged 3-5 years (Chapter 4).
   b. Investigate the efficacy of using accelerometer count thresholds to describe PA intensity in preschool-aged children (Chapter 5).
   c. Develop a robust method for reducing accelerometer data with children aged 2-5 years (Chapter 6).
3. Quantify the PA levels and socio-environmental correlates of PA in a cross-section of preschoolers residing in Auckland, NZ by completing the following:
   a. Quantify and investigate relationships between the PA patterns of children and their parent(s)/caregiver(s) using accelerometers over a 7-day period (Chapter 6).
   b. Identify demographic and socio-environmental factors that may be related to child activity (Chapters 6-7).
   c. Determine and assess relationships between body size of children and their parent(s)/caregiver(s) using waist circumference, and height and weight to calculate body mass index (BMI) (Chapter 7).
   d. Explore relationships between child body size and differing PA and inactivity profiles (Chapter 7).

Significance of the Research

Young children and their wider communities stand to gain from a better understanding of preschoolers' PA and inactivity, determinants of activity behaviours, and related health outcomes. Increased knowledge of factors related to activity can be used to guide interventions to reduce risk factors for lifestyle-related diseases and conditions, ideally resulting in reduced burden of disease.

This research provides a timely report of potential individual- and family-level factors related to objectively-assessed PA in young NZ children that may be modified or targeted for future intervention. The study in Chapter 6 was also only the second worldwide to use accelerometry to quantify the PA levels of both parents and their preschool child, and concurrently provided more detailed information about the family environment than was previously reported.

With the growing interest in researching PA in early childhood, it is critical that accurate methods of measurement are employed. The development of the novel, robust method of dealing with accelerometer data outlined in Chapter 6 enables researchers to employ a robust method to characterise PA patterns in young children, which can be translated across research studies.

As well as publication in peer-reviewed scientific journals, findings from this research have been communicated to multiple sectors and stakeholders in ECE and health, including families, government bodies, and educators. Such translation to the wider community encourages individuals and organisations to identify their role in the multifaceted determinants of PA and health in preschoolers and provides advocacy for PA prioritisation within all environments young children are exposed to.

Thesis Structure

This thesis comprises a progression of studies that are presented as sequential chapters. Chapters 2-7 have been prepared as papers for publication in peer-reviewed journals, therefore some information is repeated, and chapter formatting differs accordingly throughout. Prefaces are provided at the beginning of each of these chapters to link the chapters and outline the sequential progression of studies. Two literature reviews (Chapters 2 and 3) provide the context and impetus for the ensuing four empirical chapters. The first literature review, presented in Chapter 2, outlines the state of knowledge regarding PA in preschoolers at the outset of this thesis. The second literature review, presented in Chapter 3, provides a detailed investigation into issues related to quantifying PA in young children and identified considerable knowledge gaps. The two subsequent empirical chapters then focused on assessing PA measurement tools and developing PA measurement protocols with young children. Chapter 4 investigated the utility of pedometers for use with young children. Findings from this chapter then led to the consideration and assessment of accelerometers with preschoolers in Chapter 5. Findings from these studies informed the final measurement protocol which was developed in Chapter 6 and applied in both Chapters 6 and 7. The purpose of the final chapter is to bring together the findings and recommendations that emerged from this research, and the implications of these in the research and wider communities. Supplementary information not provided in the thesis chapters (ethics approvals, participant questionnaires, participant feedback, published papers) has been included as Appendices.

This thesis meets the terms of an Auckland University of Technology Doctoral degree by demonstrating the completion of research in a sustained self-directed investigation which contributes to knowledge in measurement of PA and associates in early childhood. An extensive examination of the wider context has led to studies of a high skill level, critical evaluation, and application. Furthermore, research findings have been disseminated to the international academic community in the form of peer-reviewed conference posters, presentations, and journal articles.

Study Delimitations

Parameters specific to this body of work are as follows:

1. Children who could not walk were excluded from all empirical studies. Considerable caution should be applied in generalising these findings across to non-walking preschool populations.

2. Ages of participants in the empirical studies ranged from 2-5 years. Considerable caution should be applied in generalising these findings across preschool populations under 2 years of age.

3. Chapters 2 and 3 encompass literature reviews published in relevant peer-review journals in 2007. Accordingly, relevant articles published after acceptance of these reviews have not been included in these chapters, however, where appropriate, more recent literature has been added to the following empirical chapters.

4. The Children's Activity Rating Scale (CARS) applied in Chapters 4 and 5 is arguably the most appropriate direct observation measure to use with preschool-aged children; however, a number of issues exist with this tool, including: direct observation methodology is inherently subjective (although stringent observer training was conducted in the current research to mitigate potential bias); the CARS was validated using energy expenditure (EE), not PA, as a criterion; and, CARS protocols may result in misinterpretation of activity level due to averaging of activity levels over 1-minute epochs.

5. By design, the study in Chapter 5 deliberately focused on moderate-to-vigorous-PA (MVPA), and so the estimates of bias will be inflated if compared to accelerometer-measured 'general day-to-day' activity.

6. None of the PA measures used in the studies provided any descriptive data on the types of activities completed or the context in which they occurred.

7. The use of accelerometers worn at the hip in Chapters 5, 6 and 7 meant that PA from upper extremity movements, load carriage, and gradient changes could not be assessed, and PA from behaviours such as cycling may have been underestimated. Also, the quality of accelerometer data has not yet been determined. Detailed analysis of the distributions and frequencies of accelerometer counts is needed in future calibration studies.

8. Assessment of children's TV watching hours was gathered using parental proxy report, which may result in proxy-reporting bias.

Research Chapter Contributions

The academic contributions and specific role of the student for the research chapters were as follows:

Chapter 2: *Physical activity in early childhood: Current state of knowledge*
Melody Oliver (60%: lead author, main contributor), Grant M. Schofield (20%), Gregory S. Kolt (10%), Claire McLachlan (10%)

Chapter 3: *Physical activity in preschoolers: Understanding prevalence and measurement issues*
Melody Oliver (70%: lead author, main contributor), Grant M. Schofield (20%), Gregory S. Kolt (10%)

Chapter 4: *Pedometer accuracy in physical activity assessment of preschool children*
Melody Oliver (70%: lead author, main contributor, 80% data collection, 100% data entry, 25% statistical analyses), Grant M. Schofield (10%), Gregory S. Kolt (10%), Philip J. Schluter (10%)

Chapter 5: *Utility of accelerometer thresholds to classify physical activity in preschoolers*
Melody Oliver (70%: lead author, main contributor, 100% data collection, 100% data entry, 50% statistical analyses), Grant M. Schofield (20%), Philip J. Schluter (10%)

Chapter 6: *Objectively assessed physical activity in preschoolers and their parents*
Melody Oliver (70%: lead author, main contributor, 70% data collection, 100% data entry, 25% statistical analyses), Philip J. Schluter (20%), Grant M. Schofield (10%)

Chapter 7: *Body size, physical activity, and television exposure in preschoolers*
Melody Oliver (80%: lead author, main contributor, 70% data collection, 100% data entry, 60% statistical analyses), Philip J. Schluter (10%), Grant M. Schofield (10%)

Chapter 2: PA in Early Childhood: Current State of Knowledge

Preface

The widely acknowledged benefits of PA for children and adults, concurrent with insufficient activity and rising lifestyle related disease prevalence, is leading researchers to consider PA in early childhood for disease prevention and establishment of healthy PA profiles from an early age. Previous studies have been conducted with preschool populations in an attempt to describe PA patterns, identify activity determinants, or determine benefits of differing facets of PA participation. This research has been conducted using medical, public health, education, and sports science measurement approaches, with little consistency between study protocols. Prior to this thesis, no studies have brought together this research in a comprehensive manner to provide a clear understanding of these issues and identify areas for future research. Accordingly, this chapter provides a systematic review and critique of the current state of knowledge regarding the benefits and determinants of PA for preschool-aged children. Barriers to activity are also explored, with a particular focus on the NZ ECE context. This chapter identifies important factors related to preschool PA and missing evidence from the existing knowledge base, thereby providing the context and direction for subsequent studies of this thesis.

Introduction

PA is defined as any bodily movement requiring EE. Within an ECE context, this refers to both fine (e.g., painting) and gross (e.g., running, skipping) body movements. PA in early childhood has traditionally been assessed using proxy questionnaires[56] or direct observation,[52] both of which are subjective measures that can lead to bias and inaccuracy.[57] More recently, motion sensors such as accelerometers have been used to gather more objective, accurate, and detailed information on the amount and level of activity in young children.[58]

The importance of PA and movement in early childhood is increasingly being acknowledged by educators, health professionals, and government departments worldwide. In NZ this is best exemplified with the Ministry of Health's *Healthy Eating-Healthy Action Implementation Plan* (HEHA) that identified the promotion of "nutrition, PA and obesity issues in preschools and schools including Köhanga Reo and Kura Kaupapa Mäori" as a key issue requiring initial attention.[59] SPARC has also identified early childhood as an important stage to address PA promotion with their launch of the Active Movement initiative in 2004. This initiative has been "designed to improve the quality, accessibility, and level of participation in PA for all children and young people in NZ".[60] The tripartite Memorandum of Understanding signed in 2004 by SPARC, the Ministry of Health, and the Ministry of Education to encourage "children to be more active and make healthy choices"[60] is further evidence of the NZ Government's prioritisation of PA in childhood.

Before moving forward with these goals, it is imperative to gather a sound knowledge-base from which to guide and inform decision making processes and interventions, and to consider what the practical implications of this knowledge may be for educators and health promoters alike. Accordingly, this paper provides a review of the current state of knowledge regarding the benefits and determinants of PA. Barriers to activity are also explored, with a particular focus on the NZ ECE context. The implications of these findings for early childhood researchers, educators, and health promoters are also discussed.

Method

Findings from the *Active Movement Scoping Exercise and Programme Evaluation* report[61] formed the basis of this chapter. Relevant information has been drawn from the report, which has been built upon, updated, and summarised. Computer database searches (MEDLINE, PsychInfo, Cinahl, Eric) and manual searches were conducted of articles in the English language literature from 1970 to 2006. Reference lists were also scanned for relevant literature. Inclusion criteria were as follows: a) subjects included children aged <5 years, and b) PA and/or concepts relating to PA were the literature focus. In line with Sallis, Prochaska, and Taylor,[62] articles were excluded that had a primary focus on sports participation, laboratory studies, case studies, expert opinion, and book chapters. Because of the paucity of research in this area, a second tier of literature was searched, encompassing doctoral dissertations and websites of national and international education associations, universities, and government departments. The studies reviewed consisted of preschool or community samples, used a variety of outcome measures and research designs, and are briefly outlined in Table 1. The terms 'young child', 'early child', and 'preschool' refer to children aged less than 5 years, 'child' refers to school-aged children, and 'adolescent' refers to children aged 13 years and over.

Table 1: Descriptive characteristics of PA and/or obesity studies in early childhood populations

Study	Sample	Ages	Measures	Results
Berenson et al.[63]	US; cohort study of 16,000 individuals	0 at baseline (1973), now aged 38y	BMI, BP, extensive CVD risk factor profiling	CVD risk factors are exhibited in early childhood & are predictive of adult CVD risk; an upward secular trend in childhood obesity has occurred
Boldemann et al.[64]	Sweden; 197 children	4-6y	BMI, UV radiation, ECE outdoor environment, environmental conditions	Quality of ECE outdoor environment (more trees, shrubbery etc.) was associated with increased PA and reduced UV radiation
Carter et al.[39]	NZ; 240 children	3y	BMI, WC, 5d accelerometry	25% of children were owt or obese; significant variation in PA levels between children was found
Dennison et al.[30]	US; 1405 boys, 1356 girls	2-4y	BMI, TV watching, TV accessibility, maternal BMI, maternal education	OR of children being owt was 1.06 for each h/d of TV/video watching; nearly 40% had a TV in their bedroom & these children were more likely to be owt & watch more TV
Dowda et al.[65]	US; 125 boys, 141 girls	3-5y	ECE centre policies, practices and overall quality; direct observation of PA	Quality of ECE centre was associated with less sedentary activity and higher MVPA
Finn et al.[66]	US; 106 boys, 108 girls	3-5y	BMI, 2d accelerometry, parental BMI & education, prematurity, participation in organised activities	Sex, prematurity, childcare centre attended, and paternal BMI influenced children's PA
Fisher et al.[27]	Scotland; 394 children	4.2±0.5y	BMI, FMS, ≤6d accelerometry	Habitual PA was weakly associated with FMS

Table 1 continued overleaf

Table 1 continued

Study	Sample	Ages	Measures	Results
Gillis et al.[28]	Canada; 80 boys, 117 girls	4-16y	BMI, 7-d PA recall	PA was negatively associated with BMI; girls were less active than boys; owt and non-owt children aged 4-7y had similar PA profiles; owt children had more sedentary activity
Gordon et al.[67]	NZ; 21 boys, 20 girls	3-7y	BMI, FM, FFM, %BF, skinfolds, circumferences	34-49% of children were obese (depending on criterion); over 60% had truncal fat levels exceeding scores for NZ children
Gustafson et al.[68]	Review of 34 international studies	3-18y (various studies)	Parental correlates of PA (various measures)	Significant correlations were found for parental support and child PA
Hancox et al.[69]	NZ; 535 boys, 502 girls at baseline	3y at baseline, followed up at 5y, 7y, 9y, 11y, 13y, 15y, 18y, 21y, & 26y	BMI, BP, VO$_{2max}$, blood cholesterol, TV watching	Average weeknight TV viewing between 5-15y was associated with higher BMI, lower fitness, & raised cholesterol at 26y; in 26y individuals, 17% of owt, 15% of increased cholesterol, & 15% of poor fitness was attributed to watching TV for >2h daily
Hernandez et al.[10]	US; 144 boys, 165 girls	3-6y	BMI, teacher reports of child behaviours & health screening tests	32% of children were obese; owt & obese children are more likely to develop risk factors for CVD & diabetes
Janz et al.[26]	US; 179 boys, 189 girls	4-6y	BMC, BMD, 4d accelerometry, parental report of child's usual PA & TV watching	PA was associated with BMC & BMD; VPA had strongest relationships with bone health
Janz et al.[70]	US; 217 boys, 250 girls	4-6y	BMI, %BF, FM, FFM, TV watching, 3-4d accelerometry	Low VPA and high TV watching were associated with fatness

Study	Sample	Ages	Measures	Results
Janz et al.[25]	US; 218 boys, 249 girls	4-7y	Bone geometry, 3-4d accelerometry, PA questionnaire	Habitual PA was associated with improved bone geometry
Khoury et al.[71]	US; 247 children	2-4y	BMI, FM, FFM, BMD, accelerometry	PA was associated with LBM and BMI
Klesges et al.[72]	US; 122 boys, 100 girls	3-6y	BMI, direct observation of PA	PA was associated with parental weight status, % time spent outdoors, and child's relative weight
Lucas et al.[73]	NZ; 78 children	3-5y	BMI, $\geq$18h accelerometry, EC environment	PA was moderately associated with indoor space; hourly PA had a weak negative association with outdoor space; 76%, 18%, and 6% of time was spent sedentary, in LPA, & in MVPA, respectively
McKenzie et al.[74]	US; 104 boys, 104 girls	4y at baseline, followed up at 5y, 6y, & 12y	Movement skills, 7-d PA recall	No significant association was found between motor skills in early childhood and PA at 12y
Moore et al.[51]	US; 63 boys, 37 girls	4-7y	8.6±1.8 days accelerometry, parental PA	Children of active mothers and fathers were 2.0 and 3.5 times as likely to be active as children of inactive mothers and fathers, respectively; children from families with 2 active parents were 5.8 times more likely to be active than children with 2 inactive parents
Moore et al.[75]	US; 63 boys, 40 girls	3-5y at baseline, followed up for 8y	BMI, skinfolds, 3-5d accelerometry	More active children had significantly smaller gains in BMI and skinfolds than less active children

Table 1 continued

Study	Sample	Ages	Measures	Results
Pate et al.[76]	US; 115 boys, 132 girls	3-5y	BMI; 1-11d accelerometry	The preschool a child attended significantly predicted VPA and MVPA; boys had more VPA and MVPA than girls
Poest et al.[77]	US; 269 boys, 245 girls	Age not stated, children were attending preschools, nurseries, & day care centres	Parental and teacher report of child's PA	Children were not engaged in VPA year round; parental PA correlated with child PA; teacher education level was associated with instructional time spent for motor development
Proctor et al.[31]	US; 73 boys, 40 girls	3-5y at baseline, followed up annually to 12y	BMI, skinfolds, % calories from fat, protein, & carbohydrate, TV watching, parental BMI & PA	Children who watched the most TV during childhood had the greatest increase in body fat over time
Reilly et al.[32]	UK; 3934 boys, 3824 girls	0y at baseline, followed up regularly to 7y	BMI at 7y, TV watching at 3y, birth weight and weight gain profiles, parental BMI, sleep hours	Parental BMI, early BMI/adiposity rebound, >8h TV watching per week at 3y, catch-up growth, weight gain in first year, birth weight, per 100g, and <10.5h sleep duration at 3y were associated with increased risk of obesity at 7y
Roemmich et al.[78]	US; 32 boys, 27 girls	4-7y	BMI, 4d accelerometry, neighbourhood environment, TV viewing time (allowance monitor)	Sex, age, socioeconomic status, adiposity, and TV watching explained 14% of the variance in PA, housing density a further 12%, and percentage of park plus recreation area a further 10% of PA variance
Sääkslahti et al.[1]	Finland; 50 boys, 55 girls	3-4y	BMI, CVD risk factors, weekend PA, FMS	PA was weakly associated with FMS and negatively associated with CVD risk factors; outdoor play and MVPA were strongest predictors of improved outcomes

Table 1 continued

Study	Sample	Ages	Measures	Results
Sääkslahti et al.[79]	Finland; 82 boys, 73 girls	4-5y at baseline, followed up for 3y	BMI, BP, serum total & HDL cholesterol, HDL/total cholesterol ratio, triglyceride concentration, PA diary	High PA was associated with reduced triglycerides, especially at 6y; girls' PA level was associated with improved cholesterol and triglyceride profiles at 6y; outdoor play in boys was related with improved cholesterol profiles at 4y
Sallis et al.[80]	US; 13 boys, 20 girls	3-5y	BMI, direct observation, parental BMI, parental self-reported PA, family CVD risk	Children spent 58% of time in sedentary activities; family CVD risk, parent VPA, and paternal BMI was associated with children's PA
Sallis et al.[52]	US; 328 families	4.4 ± 0.5y	BMI, skinfolds, social and home environment, direct observation of PA	Time spent outdoors and prompts to be active were associated with increased PA
Sallis et al.[62]	Review of 108 international studies	Categorised as either 'children' aged 3-12y, or 'adolescents' aged 13-18y)	Various measures of PA, and socio-environmental correlates of PA	Boys were more active than girls; for children aged 3-12y, PA preferences, intention to be active, perceived barriers (inverse), previous PA, healthy diet, program/facility access, time spent outdoors, and parental BMI were associated with PA level
Scantling et al.[81]	US; 48 boys, 52 girls	4-7y	BMI, %BF, FM, FFM, 6 days accelerometry	MPA & MVPA was inversely associated with body weight in girls; children in the highest tertile for MVPA weighed significantly less and had 20% less fat mass than children in the least active tertile
Sibley and Etnier[82]	Meta analysis of 44 international studies	Studies were classified by age groups (4-7y, 8-10y, & 11-13y)	Various cognitive and PA assessment measures	Larger effect sizes were found for PA and cognition in 4-7y children than the 11-13y children

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Table 1 continued

Study	Sample	Ages	Measures	Results
Specker and Binkley[83]	US; 178 children	3-5y	BMC, 3-d diet, 2d accelerometry	PA was associated with BMC, which was more pronounced with calcium supplementation
Specker et al.[84]	US; 72 infants	6m at baseline, followed up at 9, 12, 15, 18mo	BMC, 3-d diet, PA	PA was associated with BMC only in the presence of adequate calcium intake
Trost et al.[29]	US; 118 boys, 127 girls	3-5y	BMI, direct observation, 1-11d accelerometry	Owt boys were significantly less active than non-owt boys
Vaska and Volkmer[85]	Australia; 114,669 children	4y	BMI	Rates of owt and obesity in children aged 4y increased significantly from 1995−2002; in 1995 12.8% and 10.2% of females & males were owt or obese respectively, in 2002 21.4% and 17.3% of females & males were owt or obese, respectively
Vásquez et al.[86]	Chile; 12 boys, 12 girls	3-5y	FFM, FM, 3d accelerometry, EE, energy intake	PA was negatively associated with body fat; sedentary activity was higher in day care compared with the home environment
Voss et al;[44] Wilkin et al.[87]	UK; 170 boys, 137 girls	5y (Year 1 at school, mean age 4.9y)	BMI, 7d accelerometry, diet, insulin resistance, blood profiles	No information on any relationship between PA and insulin resistance has been reported to date
Worobey et al.[88]	US; 16 boys, 26 girls	4-5y at baseline, 1y follow-up	BMI, BP, 1d accelerometry	48% were owt or obese; EE was associated with BMI

BF = Body fat; **BMC** = Bone mineral content; **BMD** = Bone mineral density; **BMI** = Body mass index; **BP** = Blood pressure; **CVD** = Cardiovascular disease; **d** = day; **EC** = Early childhood; **ECE** = Early childhood education; **EE** = Energy expenditure; **FM** = Fat mass; **FFM** = Fat-free mass; **FMS** = Fundamental motor skills; **h** = Hours; **m** = Months; **LPA** = Light PA; **MPA** = Moderate PA; **MVPA** = Moderate-to-vigorous PA; **NZ** = NZ; **OR** = Odds Ratio; **owt** = Overweight; **PA** = PA; **TV** = TV; **US** = United States of America; **UV** = Ultra-violet; **VO$_{2max}$** = Maximum oxygen consumption; **VPA** = Vigorous PA; **WC** = Waist circumference; **y** = Years

Results

PA Benefits in Early Childhood

Overweight and Obesity

Weight gain, overweight status, and weight in infancy persists through the preschool years,[89] and has been associated with overweight in later childhood and adulthood.[90] Overweight and obese school-aged children are more likely to develop risk factors for cardiovascular disease and diabetes,[10] and are at much greater risk of developing adult obesity.[11] Calculated as weight (kg) / height $(m)^2$, BMI is commonly used as an indicator of body size. Age- and sex-specific BMI cut-off points have been determined for youth aged 2-18 years that relate to overweight (25 kg/m^2) and obesity (30 kg/m^2) at 18 years.[91] BMI is not an exact measure of adiposity, however, and so should be considered as a screening tool and for prevalence estimations only rather than as a diagnostic assessment of overweight or obesity.

Already a number of studies have reported a high and/or increasing prevalence of overweight and obesity in children aged less than 5 years,[67,85] including a recent cohort study children in Dunedin, NZ, whereby a quarter of the 3 year old children were overweight or obese at baseline.[39] Recent US data has shown that the prevalence of obese children aged 0 to 6 years increased from 6.3% to 10.0% from 1980 to 2001, and an the prevalence of overweight children increased from 11.1% to 14.4% during the same time period.[38] Notably, these trends were evident for all age categories of children, including infants aged less than 6 months.

A number of cross-sectional studies have shown a negative relationship between body size (overweight, obesity, or body fatness) and PA level in young children.[29,71,86] As well, specific PA variables, such as amount of vigorous PA (VPA)[70] and MVPA[81] have been related to reduced body size in early childhood. Two studies have investigated the longitudinal relationship between PA and body size.[75,88] Children classified as 'most active' in the longitudinal

Framingham Children's Study[*] had consistently less gains in body size between 4-7 years of age compared to children classified as 'least active'.[75] Nutritional intake was controlled for in the analyses, and energy intake actually increased with increasing PA level. Conversely, no difference was found between PA and weight classifications over time in another sample of US preschool children.[88] Interestingly, no relationship between energy intake and body size was found in the latter study, indicating that there may be confounding factors influencing the relationships between body size, nutrition, and PA. As such, the longitudinal association between PA and body size requires further investigation to determine whether PA influences weight status or vice-versa, while also accounting for other contributing factors to excess body size.

Inactivity has also been associated with overweight and obesity in early childhood. It is important to note that inactivity is not the exact inverse of PA. Rather, PA and inactivity are independent variables that can both have an effect on health outcomes (e.g., obesity prevalence).[92] This is because inactivity is often described and quantified as a behaviour (e.g., watching TV), rather than as reduced PA levels,[28] and these behaviours have been associated with unhealthy activities such as increased consumption of fatty foods.[92] Objectively assessed TV watching (using TV allowance monitors) has actually been positively associated with accelerometer-determined PA in young children,[78] demonstrating the ambiguous relationship between these variables.

Study findings have varied, but in general, screen time exposure (TV, video/dvd, computer, and/or game console use) of more than 2-3 hours daily has been associated with an increased risk of being overweight or obese in young children. For example, Reilly et al.[32] found that, compared with children who watched under 4 hours of TV weekly, children who watched between 4-8 hours, or more than 8 hours of TV per week were 1.37 and 1.55 times more likely to have BMI values categorised as overweight or obese, respectively. Dennison et al.[30] established that, for every additional hour of TV/video watching per day, preschool children were 1.06 times more likely to be

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[*] The Framingham Children's Study is a longitudinal study of determinants of nutrition and PA in early childhood. The study began in 1987 with 106 children aged 3-5 years from the Framingham region. Data collection has occurred on an annual basis since 1987.

categorised as overweight or obese by BMI. In the same study, children who had a TV in their bedroom were 1.31 times more likely to be in overweight or obese than children without a bedroom TV.

Using a more robust measure of body size than the former studies, Janz et al.[70] found that percentage of body fat was significantly associated with time spent watching TV. Recently, Gillis et al.[28] also found that overweight children (categorised by percentage body fat) spent significantly more time using the computer, TV, or video games than their normal weight counterparts. Only one study, the Framingham Children's Study, reported the longitudinal influence of TV watching in early childhood on body size.[31] Findings showed that at 11 years of age, children who had watched more than 3 hours of daily TV during early childhood had significantly higher BMI, triceps skinfold, and sum of five skinfolds. One NZ study has been published that has assessed TV time and body size in children.[69] Although this relationship was assessed in participants aged 5 years and older, the NZ sample and longitudinal nature of the study make it worthwhile reporting. Study findings showed that increased TV weeknight watching between 5-15 years was significantly associated with BMI. In addition, the authors estimated that 17% of overweight in the sample at 26 years could be attributed to watching TV for more than 2 hours daily during childhood and adolescence.

Collectively, the above studies provide strong evidence for the positive relationship between parent-reported screen time and body size in preschool children. This is an area for concern, particularly considering that physical inactivity has been shown to track even more strongly than PA from late childhood to early adulthood.[93] A majority of studies found were cross-sectional and used BMI as an indicator of body size. Further studies are required to longitudinally and objectively quantify time spent being sedentary and investigate the link between screen time, sedentary time, nutritional practices, socio-environmental factors, and more sensitive measures of body size. The application of proxy reports of sedentary behaviours to date are likely to result in bias. Ideally, future research should aim to utilise objective measures of sedentary behaviour, such as accelerometry and TV allowance monitors.

Although the population-wide quantification of the prevalence of participation in PA and inactivity is fundamental to understanding the role of PA in the health of young children's lives, this is an area that has not yet been explored.

Cardiovascular Disease and Type 2 Diabetes

Both cardiovascular disease and type 2 diabetes are often intrinsically linked with increased body fatness, a phenomenon termed the 'metabolic syndrome'. Individuals with this syndrome exhibit indicators of cardiovascular disease (e.g., increased blood pressure, cholesterol, low density lipoproteins, and triglycerides), diabetes (insulin resistance), and body fatness.[94] While cardiovascular disease and type 2 diabetes are normally exhibited in adult populations, cardiovascular disease risk factors have been shown to begin in early childhood and be predictive of cardiovascular disease risk in adulthood.[63] Increased insulin sensitivity has also been observed in young children as young as 4.9 years of age.[87]

To date, no published literature has reported the relationship between PA and type 2 diabetes in preschool children. The Special Turku Coronary Risk Factor Intervention Project for Babies[†] assessed the relationship between coronary heart disease risk factors (BMI, cholesterol concentrations and ratios, blood pressure, triglycerides) and parent proxy-reported PA in young children aged 4 years at baseline.[79] A negative relationship between triglycerides and high PA levels was found, especially when the children were aged 6 years. Results were also differentiated by gender; in girls a higher PA level was associated with improved cholesterol and triglyceride profiles at 6 years, whereas in boys, playing outdoors was related with improved cholesterol profiles at 4 years. While this is a large cohort study that has employed in-depth objective measures of cardiovascular disease risk factors, the use of proxy-report methods to assess PA is a limitation.

[†] The Special Turku Coronary Risk Factor Intervention Project for Babies began in Finland in 1990 with the aim to atherosclerosis development by providing lifestyle intervention to 1062 children aged 7-36 months and their families. The intervention has continued and follow-up measurements will be conducted biannually until the children are 20 years.

While there is evidence that young children may exhibit indicators of cardiovascular disease, type 2 diabetes, and the metabolic syndrome, there is a dearth of information relating to the relationship between PA and these lifestyle diseases in early childhood. Further research in this area is required before definitive conclusions can be drawn.

Bone Health

It is now well known that being active is related to the development and maintenance of healthy bones across the lifespan. The majority of the benefit is due to the forces applied to bone during activity, whereby mechanical loading causes adaptive bone responses resulting in improved bone density.[95] Achieving a peak bone density prior to puberty is integral to determining bone health (and reducing the risk of osteoporosis) in later life.

Participating in gross motor activities (bone loading) has shown greater improvements in bone mineral density than fine motor activities (non-loading) in infants[84] and toddlers aged 3-5 years,[83] however, this benefit was only observed in the presence of adequate calcium intake. The first study to investigate the influence of objectively measured habitual PA (using accelerometers) on bone density in young children was the Iowa Bone Development Study[‡].[26] Findings indicated that physically active young children had greater site-specific bone mass, bone mass density, and total body bone mass compared to their less active peers, and that time spent in VPA was most highly associated with bone measures. In more recent research (based on the Iowa Bone Development Study), Janz et al.[25] found that bone adapted positively to increased loading during daily accelerometer-determined PA in children aged 4-7 years. Importantly, this increase in bone strength was achieved through 'everyday' activity rather than specific bone loading activities or elite sport performance. A primary limitation of the latter two studies was the absence of assessment of calcium intake in the participants.

[‡] The Iowa Bone Development Study investigated the relationship between PA and bone health in 470 children from Iowa. The Study is a sub-study of the Iowa Fluoride Study, a longitudinal study of fluoride intake and dental fluorosis of 890 families.

The above studies provided cumulative evidence for a positive relationship between objectively assessed PA variables (VPA, everyday/habitual PA) and bone health in young children. This relationship may be attenuated somewhat by calcium intake, and therefore any future related studies must take this variable into account.

Motor Skill Development

Fundamental motor skills comprise the basic skills (e.g., jumping, hopping, skipping, throwing, catching) that provide the foundation for more complex movement patterns. The development of fundamental motor skills results from a dynamic interaction between the growing and maturing child, their environment, and the task requirements of physical activities performed by that child.[96] A basic mastery of these skills in early childhood has been cited as a key factor in lifelong participation in PA, recreational pursuits, and/or sports.[97]

In their study of children aged 3-4 years, Sääkslahti et al.[56] found only a weak association between PA and fundamental motor skills, however, PA was assessed subjectively with a proxy-report diary completed by parents. More recently, Fisher et al.[27] investigated the relationship between objectively measured PA (using 6 days of accelerometry) and fundamental movement skills. Findings showed significant positive relationships between fundamental motor skill development and both total PA and percentage of time spent in MVPA. These two studies provide evidence for the relationship between PA and fundamental motor skill development. Due to the cross-sectional nature of these studies, however, it is not apparent whether PA promotes fundamental motor skill development, or vice-versa.

Increased PA may be related to fundamental motor skill development in early childhood. This relationship is still not well understood as cross-sectional study designs and self-reported PA measures have been commonly applied in this area. More research is required to objectively assess this relationship over time, to determine whether PA influences level of motor skill development, or vice-versa.

Cognitive Functioning

Improved cognitive functioning has also been suggested as a benefit of PA in early childhood.[98,99] Developmental biology has provided an insight into environmental influences (including some forms of movement) on the developing brain architecture in early childhood,[98,100] with physiological changes in the brain and developmental and learning changes occurring in response to activity.[82] Activities that require crossing of the midline of the body have been promoted as being particularly important to activate both brain hemispheres in a balanced way.[101] To our knowledge, no research has yet been published that has investigated cognitive development and objectively measured PA in children aged less than 5 years, and so this relationship is still not well understood.

PA Patterns and Correlates in Early Childhood

Exactly how much activity, and what types of activities are required for health benefits in young children are yet to be fully determined. As well, our understanding of how active (or inactive) young children actually are is limited. A number of small studies have objectively quantified the PA levels of children using accelerometers, pedometers, and other motion sensors which have provided some indication of the PA patterns of this population, and are outlined in Table 1. Significant differences in PA can already be observed in children younger than 5 years, with the following shown to be positively related to one or more PA variables: male gender,[76] full term birth,[66] outdoor play time,[56] the family environment,[68] quality of ECE setting,[66,76] and neighbourhood environment.[78]

The studies of Finn et al.[66] and Pate et al.[76] provided convincing evidence for the importance of ECE environments in encouraging PA, with the preschool setting being the strongest individual predictor of PA in their samples. Specific education setting variables such as amount of time spent outdoors, quality of outdoor environment,[62,64] staff qualification level and overall centre quality[65] have been associated with increased PA in young children.

The family environment also appears integral to encouraging PA in early childhood. Parental variables such as prompting and encouragement for their child to be physically active,[52] parental PA level,[51,77] parental VPA,[80] and a lower parental BMI[66,72] have been related to the PA level of their preschool child. The first study to consider the built environment in relation to PA in young children showed that increased proximity between homes (residential density) and a greater proportion of park area in the neighbourhood was related to increased PA in their sample of 4-7 year old children, even after controlling for sex, age, family socioeconomic status, overweight status, and TV watching time.[78] Unique strengths of the latter study were the utilisation of a combination of objective measurement and analysis tools such as accelerometers, TV allowance monitors, and spatial mapping software.

NZ Research

To date, there are two studies that have objectively investigated PA in NZ preschoolers.[39,73] The Family, Lifestyle, Activity, Movement, and Eating study is a 4 year investigation of the risk factors for obesity in 3 year old Dunedin children.[39] This study has assessed PA engagement using accelerometers over 5 days and will also investigate sedentary behaviour and family attitudes towards activity and nutrition. Baseline findings showed considerable variation in PA levels between children which were not associated with gender; however, follow-up assessments have not yet been conducted so it is unclear whether this is an age-related finding. Data collection will occur annually for the next 3 years with the aim of identifying specific factors related to excessive weight gain in young children to inform intervention development.

Another study focused on PA patterns and environmental factors that may be related to PA in Auckland children aged 3-5 years utilising accelerometers.[73] Associations between PA (sedentary, light PA [LPA], MVPA) and ECE setting environment variables (space and furnishings, programme structure, activities) were determined. Indoor space was moderately associated with increased accelerometer counts per hour and total counts, while outdoor space had a weak negative association with accelerometer counts per hour. Lucas and Schofield[73] suggested these differing activity levels based on indoor and

outdoor space may have been related to scheduled activities within the education settings. Interestingly, inactivity accounted for 76% of the time measured, with 18% spent in light activity, and only 6% in MVPA. These findings provide evidence for the potentially significant role inactivity may play in young children's lives, and the importance of investigating sedentary time further.

While both of the above studies are important in contributing to the NZ evidence base of PA research in early childhood, there still remain a number of unanswered questions. For example, the Dunedin study is measuring parental attitudes towards PA, however, this is a subjective assessment that will not provide any objective evidence of the parental role in their preschool child's PA behaviours. Further, a monitoring period of 5 days may be inadequate to provide an accurate assessment of PA in this population.[102] Similarly, the Lucas and Schofield[73] study involved PA monitoring over 5 preschool days only, and no assessment of weekend PA or PA outside the preschool environment was assessed. Neither of the NZ studies assessed the relationship between the neighbourhood built environment and PA in early childhood.

Consequently, more in-depth data collection of PA patterns and potential correlates of PA in NZ preschoolers is required, to add to, and improve on, the current state of knowledge in this field. Chapters 6 and 7 outline a cross-sectional study of children aged 3-5 years that attempts to answer some of these questions.

Barriers to Activity Participation and Promotion in Early Childhood

A number of researchers have conducted qualitative research to identify barriers to the encouragement of PA and PA participation in young children via focus groups and interviews with parents, educators, health professionals, and government representatives.[61,103-105] Results have been consistent amongst studies and participants, with overwhelming agreement that PA is important in early childhood, for physical, psychological, and social wellbeing and development. While the importance of PA was acknowledged, reports of active encouragement of young children to be physically active or participating in PA with children were minimal. A number of reasons for this phenomenon were proposed by the participants of these studies, as follows: 1) some felt that children were sufficiently active without any need for further prompting or encouragement; 2) there was insufficient space, and/or a lack of covered outdoor area, for PA in the home or centre environment; 3) caregivers and educators reported lacking confidence, skills and/or knowledge required to promote PA; 4) there was a lack of logistical support for PA promotion, in terms of appropriate teacher education and funding for equipment; and 5) government regulations (noise limitations, playground safety) and centre policies (rules regarding types of activities performed indoors and outdoors, restricted planning for PA, access to TV, scheduled outdoor time, policies regarding outdoor excursions) significantly limited opportunities for PA promotion. As well, parents reported insufficient time, perceived lack of neighbourhood safety (road safety and 'stranger danger', especially in underserved communities), expense of structured programmes, lack of community role models, and children's preferences for sedentary activities as key barriers to PA in early childhood.

Especially pertinent to the NZ context, findings from consultation with stakeholders in ECE and health (early childhood and tertiary educators, government representatives, health promoters, parents, researchers) for the *Active Movement Scoping Exercise and Programme Evaluation* showed that people and general society were fundamental barriers to PA promotion and encouragement in early childhood.[61] At the macro level, societal attitudes towards prioritisation of academic learning and achievement over play and PA, and a general cultural shift towards inactivity and a preference for sedentary

pursuits were identified as constraints to promoting activity in young children. Limited information and support for early childhood educators was highlighted, particularly in terms of pre-service and in-service professional development, and to a lesser degree, funding for equipment and training. While a number of programmes were identified that facilitated PA in ECE settings, these programmes were not being rigorously evaluated, nor were they being efficiently disseminated throughout the early childhood community. At an individual level, the attitudes, behaviours, knowledge and available time of both parents and early childhood educators were identified as key barriers to PA promotion. Specifically, parental prioritisation of academic (literacy and numeracy) learning outcomes and less regard for the potential learning opportunities and social and holistic benefits gained from PA posed a considerable challenge for early childhood educators. Concurrently, educators themselves felt ill-equipped to promote PA appropriately, and many reported being inactive themselves.

Summary and Implications for NZ ECE and Research

PA may confer a multitude of benefits to the young child. There is sufficient evidence to suggest a negative relationship between PA and body size, and strong evidence for a positive association between sedentary activity and body size in early childhood. PA has also been associated with improved bone density in young children, particularly in the presence of adequate calcium intake. A positive relationship has been exhibited between PA and fundamental motor skill development in toddlers.

A number of questions remain unanswered. There is a dearth of research investigating the interactions between PA and cognitive development, insulin resistance, and cardiovascular disease risk factors in early childhood. The influencing variables in the relationships between PA and health outcomes need to be determined in longitudinal research, and whether these relationships track over time is yet to be established. Understanding the overall prevalence of PA and sedentary behaviours in young children is essential.

Further research is necessary to objectively quantify time spent being physically active and sedentary, and to investigate associations between PA, screen time, sedentary time, nutritional practices, and health outcomes in early childhood. The level of PA required for health gain in young children, and variables that can either be modified or targeted for PA intervention in this population group need to be identified.

The current state of knowledge for this population indicates that important PA variables to assess are amount of VPA and sedentary time. Family and ECE settings appear important environments to investigate further in terms of influencing PA and being amenable to change. More work is required to understand the influence of the built environment on PA in early childhood. Early childhood educators require ongoing logistical support to promote and encourage PA, including pre-service and in-service training, and government legislation and centre policies that encourage PA promotion and participation for preschool children. Improved societal knowledge and attitudes regarding the fundamental role of PA in healthy development and learning is integral. Inter-sectoral approaches (between health, education, and researchers) and effective lines of communication are required to disseminate best practice approaches and research findings throughout the ECE community, and to ensure a consistent PA message is promoted. The SPARC Active Movement Initiative is an ideal means by which to meet some of these needs, particularly in terms of teacher training and societal education, advocacy, and improved communication and collaboration between agencies and disciplines.

This issue is of importance to all New Zealanders at an individual, community, and national (policy) level. Given the current dearth of robust research in this area, it is imperative that quality research to improve our knowledge and understanding of PA in the early childhood years is considered a priority area for educators and health promotion researchers in NZ and internationally.

Chapter 3: PA in Preschoolers: Understanding Prevalence and Measurement Issues

Preface

Findings from Chapter 2 indicate that PA in early childhood may confer considerable health gain, including improved bone health and a reduced risk of being overweight, while increased sedentary time may have a negative influence on physical health. There is a paucity of information pertaining to PA and cognitive development, insulin resistance, and cardiovascular disease risk factors for this age group. Exactly how much PA is required, and what types of activity are important for health gain in young children is yet to be determined. As well, there is limited information regarding the activity profiles of preschool children, and the determinants of both PA and sedentary behaviour.

Key to understanding these factors is the ability to accurately quantify PA in preschoolers, and to recognise measurement issues specific to these children. Accurate PA quantification in preschoolers is fundamental to establish PA prevalence, dose-response relationships between activity and health outcomes, and intervention effectiveness. To date, best practice approaches for PA measurement in preschool-aged children have been relatively understudied compared with older, school-aged children, and no comprehensive review of PA measurement in early childhood has been published. As such, this Chapter provides a timely contribution to this research field. A comprehensive review and critique of PA measurement tools for preschoolers is provided, as well as an overview of measurement issues relevant to preschool-aged children and directions for further research.

Introduction

Regular participation in PA has been clearly established as being integral to health and wellbeing in school-aged children. There is evidence that obesity,[106,107] inactivity,[13] and PA[14] may all track from childhood to adolescence and adulthood, and thus recent research has begun to focus on the importance of PA in the preschool years. The limited evidence available suggests that increased PA in preschoolers is associated with a reduced risk of being overweight or obese[29,71,75] and less likelihood of having one or more risk factors for cardiovascular disease.[79] Improved bone health[25,26] and fundamental motor skill development[27] have also been associated with higher levels of PA in this population. Conversely, higher levels of inactivity in preschool-aged children have been related to an increased risk of being overweight or obese.[28,31,35]

Dose-response relationships between PA and health risk factor reduction for young children are yet to be determined. As well, the actual prevalence of PA participation in young children is not well understood, either at a cross-sectional or population level. There is a paucity of comprehensive information regarding the amount of habitual PA that young children accumulate, the types and intensities of activity participated in, and time spent in sedentary pursuits.

The underlying issues facing researchers trying to understand both prevalence and dose-response relationships are based on being able to measure amounts and types of PA that young children engage in. Researchers require a robust, reliable, and valid method which is recognised as being 'best practice'. In practical terms, the greatest challenge is identifying what to measure, how to define what is measured, and how to ensure consistency across studies. For example, recent approaches for young children have included measuring PA in time, EE per unit of time, frequency of activity (activity counts), step counts, heart rate, maximal oxygen consumption (VO_{2max}), carbon dioxide production, or other methods combining some of these units.

The purposes of this chapter are to review methods used to assess PA in young children and to suggest directions for future research. Understanding PA measurement in preschoolers is essential as this provides the basis for examining health benefits of activity in this population, setting PA recommendations, gathering prevalence data, and establishing intervention efficacy. Where necessary, the review has been widened to consider youth in general with a goal of understanding, by employing a more extensive database, the range of measures that might be appropriate for this younger population.

A novel approach to categorising PA measurement tools is used. In the literature, the term 'criterion measure' has generally been used to refer to tools that are considered exact indicators of PA engagement.[57] This concept is problematic, as currently none of the measures classified as a PA 'criterion' in the preschool literature can be considered precise assessments of PA. Hence, rather than dichotomising measures as either being 'criterion measures' or not, we suggest the following categories to describe tools that might be used for validating PA measures (in order of most to least specific): 1) objective measures of PA, 2) subjective measurements of PA, and 3) methods of EE calculation. Motion sensors (monitors worn by the participant that collect information on body movements) are considered objective measures of human PA. While EE is undisputedly a consequence of PA participation, this construct has been considered as a separate variable to PA in the current paper, and a justification provided for this in the EE section below.

Method

Computer searches (MEDLINE, PsychInfo, Cinahl, Eric) and manual searches were conducted of articles in the English language literature from 1980 to 2007. Keywords included early childhood, measure, movement, PA, preschool, reliability, young child, valid. Search terms included a combination of keywords, for example 'PA' AND (preschool OR young child OR early childhood) AND (measure OR valid OR reliability). Because of the limited published literature in this field, broad inclusion criteria were applied as follows: (a) subjects were aged less than five years, and (b) subjects' PA and/or the measurement tool was assessed or reported.

In contrast to the earlier review of children's PA measurement by Sirard and Pate,[57] all validation studies have been included, irrespective of the comparison measure used. With respect to age, studies were considered if their sample included both preschool children and children aged five years and older. No upper age cut-off was used. While published abstracts have been included, articles were excluded that had a primary focus on sports participation, laboratory studies, case studies, expert opinion, book chapters, and dissertations.

Results

Objective Measures of PA

Studies identified from the search that have assessed PA in preschool children are summarised in Table 2. This table also provides an outline of the differing methodologies used to assess PA in preschoolers to date. Where studies have used both objective and subjective measures of PA, only the objective measurements have been reported, as this is likely to yield the most accurate information on PA engagement. Essentially, this is because objective measures can mitigate any potential inaccuracies resulting from self- or proxy-report bias[49] and bias resulting from researcher coding of PA.[50] As can be seen from Table 2, motion sensors (accelerometers and pedometers) were most frequently used to assess activity in young children (71%).

A key advantage of using motion sensors is that data collected are likely to be free from researcher bias. Other advantages include low researcher and participant burden, the ability to quantify PA over extended periods of time, and affordability as compared with direct observation methods. The primary disadvantage of using motion sensors is the context in which PA occurs cannot be determined. The utility of pedometers and accelerometers for use with preschoolers is discussed further below.

Table 2: Preschool PA measurement studies[a]

Study	Protocol	Participants	Key activity findings
Accelerometer (ActiGraph)			
Cardon and De Bourdeaudhuij[108]	4d, including 2 weekend days	76 children	Average SED and MVPA/d was 9.6h and 34 min, respectively; weekday total activity was higher than weekend activity (P<0.001); boys were more active than girls (P<0.05)
Cliff et al.[109]	≤7d	26 girls, 32 boys; mean 4.29y	On average, all children accumulated >60 min MVPA/d; 3.5% did not achieve >60 min MVPA on every monitoring day
Fisher et al.[110]	18.0-217.3h, week and weekend days	108 girls, 101 boys, 3-5y	74.2-79.5%, 17.0-21.7%, and 2.1-4.1% of activity was SED, LPA, and MVPA, respectively; seasonal differences were observed for total (P<0.001), SED (P<0.001), LPA (P<0.001), and MVPA (P<0.01)
Fisher et al.[27]	6d	185 girls, 209 boys; 3-5y	76.3%, 20.3%, and 3.4% of PA was SED, LPA and MVPA, respectively; mean accelerometer counts per minute were 769±192; boys were more active than girls
Heelan and Eisenmann[34]	≥4d, including 1 weekend day	52 girls, 48 boys; 4-7y	Mean±SD min/d spent in MPA, VPA, and MVPA were 241.5±48.8, 32.3±17.1, and 273.8±59.1, respectively
Jackson et al.[111]	3d, including 1 weekend day, follow-up at 1y	52 girls, 52 boys; 3y at baseline; 30 girls, 30 boys at follow-up	Boys and girls had means of 777±207 and 651±172 counts/min at baseline, respectively; children at follow-up had a mean of 849±252 counts/min (compared with 669±165 at baseline); the tracking rank order correlation coefficient of total activity counts over 1y was r=0.40 (P<0.001); total PA increased over 1y (P<0.001); boys were more active than girls (P<0.001)
Janz et al.[25]	4d, including 1 weekend day	232 girls, 204 boys; 4-7y	Boys had 244±43, 267±44, and 38±19 min/d of SED, MPA, and VPA, respectively; girls had 251±48, 262±44, and 28±14 min/d of SED, MPA, and VPA, respectively; boys were more active than girls (P<0.05)

Table 2 continued overleaf

Table 2 continued

Study	Protocol	Participants	Key activity findings
Accelerometer (ActiGraph)			
Janz et al.[26]	4d, including 1 weekend day	189 girls, 179 boys; 4-6y	Boys had more total PA and VPA than girls (P<0.05)
Janz et al.[70]	4d, including 1 weekend day	231 girls, 203 boys; 4-6y	Mean counts per minute for boys and girls were 773.6±176.0 and 702.6±154.8, respectively; mean min/d of MVPA and VPA were 277.1±50.8 and 31.8±16.3 for boys, and 263.0±48.2 and 24.6±13.0 for girls, respectively; boys had more total PA, MVPA, and VPA than girls (P<0.05)
Kelly et al.[112]	7d	22 girls, 18 boys; 4-5y	Boys of higher socioeconomic status accumulated less total PA than boys of lower socioeconomic status (P<0.05)
Kelly et al.[113]	3d at baseline, 7d at 2y follow-up	21 girls, 21 boys; mean 3.8y at baseline	80.5% and 74.1% of activity was SED, 2.2% and 4.1% was MVPA at baseline and follow-up, respectively; % agreement and κ for PA, MVPA and SED from baseline to follow-up were 38% and 0.17, 41% and 0.01, and 26% and 0.21, respectively
Lucas and Schofield[73]	$\geq$18h	78 children; 3-5y	76%, 18%, and 6% of activity was SED, LPA, and MVPA, respectively; boys were more active than girls (t=2.56, P=0.01)
Metallinos-Katsaras et al.[114]	4.7-7d	30 girls, 26 boys; 2-5y	61%, 35%, and 4% of activity was SED/LPA, MPA, and VPA, respectively; boys were more active than girls (P<0.05); non-overweight children had significantly more very vigorous min and very active min of PA than overweight children (4.6 and 32.1 min vs. 2.6 and 22.9 min respectively, P<0.05)
Pate et al.[76]	1-11 weekdays	132 girls, 115 boys; 3-5y	42.1±5.8, 10.5±3.2, 7.7±3.1, and 1.9±1.1 min/h were spent in SED, LPA, MVPA, and VPA, respectively; preschool was a significant correlate of MVPA and VPA; boys had more MVPA (P=0.01) and VPA (P=0.001) than girls; Black children had more VPA than white children (P=0.04)

Table 2 continued

Study	Protocol	Participants	Key activity findings
Accelerometer (ActiGraph)			
Reilly et al.[115]	6d at 0 and 6mo	272 girls, 273 boys; 4y at baseline	Mean counts/min, %SED, and % MVPA for intervention and control groups at baseline were 732 counts, 69.3%, and 2.6%, and 809 counts, 66.9%, and 3.0%, respectively; mean counts/min, %SED, and % MVPA for intervention and control groups at 6mo follow-up were 809 counts, 67.0%, 3.5% and 899 counts, 62.9%, and 4.1%, respectively
Reilly et al.[58]	2-3d at 3y; 7d at 5y	73 girls, 77 boys, 3 and 5y	79% and 76% of activity was SED, and 2% and 4% was MVPA, at ages 3 and 5y, respectively
Roemmich et al.[78]	4d	27 girls, 32 boys; 4-7y	Mean counts/min for boys and girls were 779±230 and 683±178, respectively
Trost et al.[116]	20 preschool sessions of 2.5h each	19 girls, 23 boys, 3-5y	Mean total counts, MPA min, and VPA min for the 2.5h sessions were 171,100±29,700, 12.4±3.1, and 18.3±4.6, respectively; children aged 3y had significantly less PA than children aged 4 or 5y
Worobey et al.[117]	90 min	40 children; 4-5y	Mean activity counts for Head Start and University preschool children were 111,661±61,235 and 279,157±98,251, respectively ($P<0.0001$)
Worobey et al.[88]	6.75h in fall and spring	26 girls, 16 boys; 4-5y	Non-overweight children accumulated 177,956±60,714 and 250,950±96,213 activity counts in fall and spring, respectively; overweight children accumulated 206,314±91,301 and 250,336±72,272 activity counts in fall and spring, respectively

Table 2 continued

Study	Protocol	Participants	Key activity findings
Accelerometer (ActiGraph); DO (OSRAP)			
Trost et al.[29]	1-11 days (DO for 1h on 3d)	127 girls, 118 boys; 3-5y	Non-overweight girls and boys spent 41.6±12.5% and 47.6±12.7% of time in MVPA, respectively; overweight girls and boys spent 42.2±12.8% and 39.0±12.5% of time in MVPA, respectively
Accelerometer (Actiwatch)			
Butte et al.[118]	3d	520 girls, 510 boys; 4-19y (14% were 4-5y)	Mean counts/d, %SED, %LPA, %MPA and %VPA for boys were 236,000 counts, 38%, 51%, 10%, and 0.4%, respectively; for girls these values were 216,000 counts, 38%, 54%, 8%, and 0.2%, respectively; boys had significantly more total PA and MPA, and significantly less LPA than girls (P<0.05)
Finn and Ullmann[119]	3 weekdays	16 girls, 12 boys; 3-5y	No differences between seasons
Finn et al.[66]	48h, weekdays	108 girls, 106 boys; 3-5y	Mean daily sensor counts were 263,000±7,000 and 285,000±8,000 for girls and boys, respectively; 4.5 ± 2% and 5.2 ± 0.2% of activity was VPA for girls and boys, respectively; boys were more active than girls (P<0.001)
Firrincieli et al.[120]	6-7d	33 girls, 21 boys; 3-5y	Asthmatic and non-asthmatic children accumulated 1,041 and 1,610 bouts of 10 min continuous PA respectively, normalised over 7d
Specker and Binkley[83]	48h at 0, 6, and 12mo	84 girls, 94 boys; 3-4y	12.1-14.0% and 4.5-5.4% of activity at baseline was MVPA and VPA, respectively; mean daily counts for study groups at baseline were 259,000-297,000

Table 2 continued

Study	Protocol	Participants	Key activity findings
Accelerometer (Caltrac)			
Moore et al.[31,51,75,121]	3-5d annually for 7y	40 girls, 63 boys; 3-5y at baseline	Caltrac counts/h for children in the lowest, middle, and highest PA tertiles were 8.5±0.8, 10.2±0.4, and 12.5±1.2, respectively
Accelerometer (RT3)			
Claytor et al.[122]	3d	267 children, 2-4y	Weekday activity was higher than weekend activity; boys were more active than girls ($P<0.01$)
Claytor et al.[123]	3 days, including 1 weekend day	117 girls, 150 boys; 2-4y	Maternal leisure time PA was associated with children's activity vector magnitude/min ($r=0.13$; $P<0.03$)
Khoury et al.[124]	3d	107 girls, 136 boys; 2-4y	Rest time during waking hours was negatively associated with vector magnitude/min ($P<0.05$)
Vásquez et al.[86]	3d, including 1 weekend day	9 girls, 10 boys; 3-5y	%SED/LPA was 52%, 54%, and 62% during weekend days, weekdays at home, and at day-care, respectively; %MPA during weekend days and weekdays was 3% and 4%, respectively

Table 2 continued

Study	Protocol	Participants	Key activity findings
DO (BEACHES-SCAN)			
Broyles et al.[125]	1h home, >30 min preschool, 12 x over 2.5y	167 girls, 184 boys; 4.4y at baseline	Children had higher PA indexes for recess than at home (0.078-0.084 vs. 0.058-0.064)
Elder et al.[126]	1h home, 10 x over 2y	138 girls, 153 boys; 4y at y 1	Boys and girls complied with parental prompts for PA in 60% and 59% of intervals, respectively
McKenzie et al.[127,128]	1 x recess period (~26 min at baseline, ~14 min at follow-up)	132 girls, 155 boys, 4y at baseline, 6y at follow-up	PA level increased over time (from 58.9% and 41.1% of time spent SED and in MVPA at 4y, respectively, to 52.5% and 47.5% SED and MVPA at 6y, respectively; $P<0.002$)
Sallis et al.[129]	1h home, >30 min preschool/school, 10 x over 2y	167 girls, 184 boys, 4.4y at y 1	Home PA tracked more over time than preschool/school PA (r=0.15 for single days, and r=0.36 for 4 day mean)
Sallis et al.[52]	4 x 1h observations	347 children; 4y	Mean intervals of time outdoors was 15.5±15.5%; mean kcal/kg/min (reported as PA) was 0.060±0.008
DO (CARS); HR			
Jago et al.[130]	2.5-2.7h on 3 consecutive years	76 girls, 73 boys; 3-4y at year 1	88%, 62%, and 60% of activity was SED, and 12%, 7%, and 10% was MVPA in years 1, 2, and 3, respectively; SED in year 1 predicted PA in years 2 and 3

Table 2 continued

Study	Protocol	Participants	Key activity findings
DO (CARS)			
Baranowski et al.[131]	6h on ≥4d	101 girls, 90 boys, 3-4y	Overall mean PA was low (CARS level of ~2); outdoor play was associated with PA; gender, month, and location accounted for 75% of variance in PA; boys were more active than girls
DuRant et al.[132]	≤4d, 6-12h/d	101 girls, 90 boys; 3-4y	Mean PA level was highest during outside play, and lowest during the longest bout of TV watching (CARS level 2.38 vs. 1.48)
DO (FATS)			
Klesges et al.[133]	1h	15 girls, 15 boys; 22-46mo	28%, 65%, and 7% of activity was minimal, moderate, and extreme, respectively; parental prompting was associated with extreme PA (P<0.01); boys were more active than girls (P<0.05)
Sallis et al.[80]	30 min	20 girls, 13 boys; 3.9 ± 0.7y	58%, 31%, and 11% of PA was SED, MPA and VPA, respectively
DO (OSRAP)			
Dowda et al.[65]	1h x 3 weekdays	141 girls, 125 boys; 3-5y	Centre variables and policies were associated with MVPA (P<0.04); centre quality was associated with less SED (P=0.04)

Table 2 continued

Study	Protocol	Participants	Key activity findings
DO (SCAN-CAT)			
Eck et al.[134]	1h	83 girls, 104 boys, 3-4y	Children with one or more overweight parent(s) had marginally more stationary PA (P=0.07) and marginally less total PA (P=0.06) than children with no overweight parents
Klesges et al.[72]	1h at home	100 girls, 122 boys; 3-6y	Outdoor time, child relative weight, and interacting with others were positively associated with PA; parental overweight was negatively associated with child's PA
Pedometer (Walk4Life)			
Carson and Ayers[135]	Not supplied	Preschool children	Mean weekly step counts were 44,423±11,888 and 68,272±22 362 for the control and intervention groups, respectively (P<0.001)
Pedometer (Yamax SW/DW Series)			
Al-Hazzaa and Al-Rasheedi[136]	3d	115 girls, 109 boys; 3.4-6.4y	Average daily step count was 6,773; boys were more active than girls (P<0.05)
Boldemann et al.[64]	12 weekdays	197 children; 4-6y	Developed outdoor landscape (trees and shrubbery) was associated with PA (P<0.001); boys were more active than girls (8.8-37.2 and 8.9-30.0 steps per min, respectively; P<0.001)
Cardon and de Bourdeaudhuij[137]	4d, including 2 weekend days	63 girls, 59 boys; 4-5.9y; ActiGraph accelerometer sub-sample of 39 girls, 37 boys; 4-5.9y	Average daily step count was 9,980±2,605; weekday activity was higher than weekend activity (P<0.001); 13 874 steps/day was identified as being comparable to accumulating to 60 min MVPA/day

Table 2 continued

Study	Protocol	Participants	Key activity findings
Videotape (focal individual sampling approach)			
Hart and Sheehan[138]	24 x 30s observations over 12 weekdays	20 girls, 20 boys; 2-5y	Children had less PA in a contemporary playground setting (fixed equipment, landscaped, etc.) compared with a traditional (less structured, more movable equipment) playground

[a]Only studies that have assessed PA (as opposed to energy expenditure) have been included in this table. This table does not include studies where questionnaires were the only form of activity measurement nor those with a primary focus of validating a PA measurement tool

ActiGraph = uni-axial accelerometer, previously known as the CSA 7164; **Actiwatch** = bi-axial accelerometer; **BEACHES** = Behaviors of Eating and Activity for Child Health: Evaluation System; **CARS** = Children's Activity Rating Scale; **CAT** = Children's Activity Timesampling method of observation; **DO** = direct observation; **FATS** = Fargo Activity Timesampling Survey; **HR** = heart rate telemetry; **LPA** = light PA; **MPA** = moderate PA; **MVPA** = moderate-to-vigorous PA; **OSRAP** = Observation System for Recording Activity in Preschools; **PA** = PA; **RT3** = tri-axial accelerometer; **SCAN** = Study of Children's Activity and Nutrition; **SED** = sedentary activity; **TV** = TV; **VPA** = vigorous PA

Pedometers

Pedometers are small devices mounted at the hip, ankle, or wrist that use mechanical motion sensors to quantify PA in terms of accumulated steps. These sensors are used to objectively quantify PA, specifically ambulatory activity. Pedometers are easy to use, do not require researcher or participant training or software, and their 'currency' of steps is easily understood by children and adults alike. During the past decade, several commercially available brands of electronic pedometers have become available, for example, the Yamax DW/SW series (Tokyo, Japan), NL2000 (New-Lifestyles Inc., MO), Freestyle Pacer (Camarillo, CA), and Eddie Bauer Compustep II (Redmond, WA). Collectively, the results of several studies have concluded that the Japanese developed Yamax DW or SW series (200-700) and the NL2000 are the most accurate for use with adults.[139,140]

Although not primarily a pedometer validation study, Cardon and de Bourdeaudhuij[137] provided some evidence for the convergent validity of the Yamax SW-200 in 76 children aged 4-5.9 years. A significant correlation (r=0.73) was measured between total daily steps and minutes of MVPA assessed using the MTI 7164 ActiGraph. Furthermore, a regression equation was developed to identify a value of 13,874 daily steps that was comparable to the accumulation of 60 minutes of MVPA throughout the day.

The earliest study to consider pedometer validity in preschoolers was that of Nishikido et al.,[141] who found that PA assessed with the Yamasa AM-5 pedometer was moderately to strongly correlated (r=0.69-0.83) with frequency of running activities in 50 kindergarten children. The Walk4Life pedometer was later successfully used to detect difference in PA change between classes that received a PA intervention, and comparison (control) classes.[135] While neither of these studies actually validated pedometers against other PA measures, they nonetheless provided some evidence for the viability of pedometer use with preschoolers.

Three studies were found that have since investigated pedometer validity in preschoolers.[142-144] Louie and Chan[142] used Yamax SW-200 pedometers to measure PA in 148 children during 25 minutes of free-play activity in three Hong Kong preschools. The CARS[145] was used in this study to validate the pedometer use, and 30 children were also randomly assigned to wear 1 pedometer on either hip to provide an indication of pedometer reliability. A significant moderate correlation (r=0.64) was observed between the total pedometer counts and CARS scores, while no significant difference was found between pedometers worn on either left or right hips.

McKee et al.[143] also validated the Yamax SW-200 using the CARS in 30 children aged 3-4 years. Measurement of self-selected activities was conducted for 1 hour in a nursery school setting, and results for each 3-minute interval compared. Findings showed moderate-to-strong within-child correlations for the 3-minute intervals of pedometer and direct observation results, ranging from r=0.64-0.95, with a median of r=0.86. In a more recent study of 13 preschool children, Oliver et al.[144] assessed the validity of the Yamax SW-200 using the CARS in unstructured free play sessions of 35 minutes duration. Moderate associations were observed between direct observation and pedometry (r=0.59, P=0.04). When the level of agreement[146,147] between the PA measures was assessed in the same study, the accuracy of pedometry in assessing free-living activity became questionable.

This contradiction of findings is an example of the problematic nature of using correlations to establish criterion or convergent validity in PA measurement research. Fundamental issues with this approach are that correlational approaches measure only the strength of a relationship between measurement tools, they are not affected by scale, and any systematic differences between tools is overlooked. As well, the association observed depends on the range and distribution of the true quantity of the variables in the sample.[146,147] Consequently, two measures may have strong and statistically significant correlations, but in actuality the results gathered from the 2 measures may have low agreement. Using Bland-Altman methods (e.g., limits of agreement, 95% prediction intervals) as applied in Oliver et al.[144] study can mitigate these issues.[146,147]

The validity and reliability of pedometers worn at the right hip, left hip, and back were also assessed in the Oliver et al.[144] study using observed step counts while walking along a straight line over three pace conditions (slow walk, normal walk, run). Limits of agreement and prediction intervals for directly observed step counts were wide (15-44 steps over 29 m) for all pedometer placement sites and pace conditions. In particular, pedometers worn at the back were less accurate than pedometers worn at either hip, and results were more variable for all pedometers during the slow walking condition. The authors proposed that pedometers may be best suited for general assessment of preschoolers' accumulated activity, rather than for research purposes, and that hip placement was preferable to back placement.

Collectively, these six studies provide an indication of the feasibility of using pedometers with preschool children. Correlational studies have shown at least moderate associations for pedometry with direct observation and accelerometry, although this method of data analysis may be inherently flawed for establishing validity. The one study that has used an alternative method of data analysis to reduce issues associated with correlations showed wide limits of agreement and prediction intervals,[144] however, these findings were limited by a small sample size.

Accelerometers

Accelerometers are lightweight, waterproof motion sensors that record detailed information on movement counts, PA intensity, and date and time of activities. Modern motion sensors (e.g., ActiGraph, Actical, Caltrac, RT3) use piezoelectricity to register accelerations, whereby crystalline structures are subjected to motion and generate a level of voltage in direct relation to the level of motion/stress. As shown in Table 2, more than half of the identified studies in preschool PA (63%) have utilised accelerometry, with a majority of these (21 studies) having used the Manufacturing Technologies Inc. 7164 ActiGraph (MTI; Shalimar, FL) (previously the Computer Science and Applications [CSA] 7164 ActiGraph). Five other devices have been used with this population, the Actical and Actiwatch accelerometers (Mini-Mitter Co., Inc. Bend, OR), the Caltrac (Muscle Dynamics Fitness Network, Torrence, CA), the Large Scale Integrated PA monitor,[148] and the RT3 (Stayhealthy Inc., Monrovia, CA) (previously the TriTrac R3D). These instruments vary in size, weight, and the number of planes (horizontal, vertical, diagonal) that movement is measured. All accelerometers measure accelerations in the vertical plane, as this has been shown to be most important for measuring ambulatory movement.[148] The RT3 also measures accelerations in the horizontal and diagonal plane creating a 3-dimensional measure of movement, while the newer Actical accelerometers contain piezoelectric transducers that are sensitive to accelerations caused by bodily movement in multiple planes of motion, with one end of the sensor fixed and the other end able to move about freely. This technology means that the Actical is the only commercially available accelerometer that can provide an assessment of omni-directional activity. Readers are directed to the reviews by de Vries et al.,[149] Rowlands,[150] and Sirard and Pate[57] for detailed overviews of accelerometers used with children. Whether multi-directional accelerometry is best suited for quantifying the characteristically variable activities of young children in free-living conditions is yet to be established. Research findings comparing single axis accelerometry with multi-axis accelerometry in school-aged children have been unclear.[151,152] Correlational approaches have been the predominant method of analysis in the accelerometry literature to date. As previously discussed, this methodology is problematic in determining accuracy of activity measurement tools.

Table 3 summarises the 18 studies found that investigated accelerometer validity in preschool populations. Two papers reported Actical accelerometer validity findings using oxygen consumption (VO_2) as a criterion assessment.[153,154] Strong associations were observed for the Acticals worn both at the back and hip, and within laboratory and unstructured free play settings. Direct observation was the only measure utilised to assess the validity of Caltrac accelerometers in preschool children in the 5 studies found,[49,155-158] issues of which are discussed in the direct observation section below. Associations were variable both within and between studies (r=0.25-0.95), and differences were observed between indoor and outdoor play (r=0.47-0.56 and r=0.16-0.48, respectively).[158] The weaker associations found for outdoor play might have been due to difficulties in accurately observing children in the outdoor (and possibly less restricted) settings, or because activities that young children participate in whilst outdoors are not as well assessed by the Caltrac as indoor activities.

In contrast, the ActiGraph (also known as the CSA/MTI 7164) has been relatively well-researched in 6 studies using a variety of settings, measurement durations (up to 3 days),[159] and differing criterion measures (direct observation, doubly labelled water, VO_2). Associations have ranged from r=0.33 for doubly labelled water,[159] to r=0.75-0.82 for VO_2,[153,160] and r=0.52-0.87 for direct observation.[161-164] The weaker association found for doubly labelled water may be related to the increased duration of PA assessment (3 days), compared with a maximum of 1 hour for direct observation.[161] Another explanation may be that these monitors do not associate well with EE determined by the doubly labelled water method. This phenomenon was observed in a validation study of Actiwatch accelerometers using doubly labelled water as a criterion measure, whereby a weak, non-significant association was found between the Actiwatch and total EE as determined with doubly labelled water.[165] Also, the study protocol involved a measurement period of 7 days, which was substantially longer than other studies that assessed the validity of Actiwatch accelerometers (26 minutes-6 hours).[164,166,167] Relationships between PA measured using the Actiwatch and by direct observation were highly variable, ranging from r=0.03-0.92 for data using 1-minute epochs,[164,166,167] and r=0.33-0.79 for data using 15-second epochs.[166]

Table 3: Validation of accelerometer use in preschoolers

Study	Measurement protocol	Variables	Participants	Criterion	Validity	Reliability
Actical						
McIver et al.[153]	10min rest, 5min walk at 3.2 km/h, 4.8 km/h, and jog at 6.4 km/h	Counts/activity stage	16 girls, 14 boys; 3-5y	VO$_2$ (portable metabolic analyser)	r=0.86 for hip; r=0.87 for back	NA
Actical; 15s epochs						
Pfeiffer et al.[154]	3 structured activities in laboratory setting; unstructured indoor and outdoor play; 20 min	Mean counts/min; MVPA; VPA	11 girls, 7 boys; 4.4$\pm$0.7y	VO$_2$ (portable metabolic analyser)	r=0.89 for lab activities; r=0.59 for unstructured play; κ=0.46 for MVPA; κ=0.71 for VPA	NA
ActiGraph; 15s epochs						
McIver et al.[153,160]	10min rest, 5min walk at 3.2 km/h, 4.8 km/h, and jog at 6.4 km/h; cross-validation 20 min indoor and outdoor play	Counts/activity stage	16 girls, 14 boys; 3-5y	VO$_2$ (portable metabolic analyser)	r=0.82 across all activities; cross-validation ICC r=0.57	NA
Sirard et al.[161]	Study 1: 5 x 3 min structured activities for validity and hip placement reliability	Study 1: SED, LPA, MPA and VPA cut-offs based on CARS	Study 1: 5 girls, 11 boys	DO (modified CARS)	Study 1: sensitivity and specificity for cut-offs were 86.7-100% and 66.7-100%, respectively;	r=0.86 for left and right hips
	Study 2: day care setting; 1h x 1-3 days for validity	Study 2: mean counts/15s and cut-offs from study 1	Study 2: 144 girls, 125 boys; 3-5y		Study 2: r=0.46-0.70	

Table 3 continued

Study	Measurement protocol	Variables	Participants	Criterion	Validity	Reliability
ActiGraph; 1 min epochs						
Fairweather et al.[162]	Structured activity session; 40-50 min	Mean counts/min	8 girls, 3 boys; 3-4y	DO (CPAF)	r=0.87	r=0.98-0.99 with *in vitro*; r=0.92 with hip placement, but left vs. right hip differed (P<0.05)
Kelly et al.[164]	Structured play class, 39-45 min	Mean counts/min for total time; mean minute-to-minute counts/min	48 girls, 30 boys; 3-4y	DO (CPAF)	r=0.72 for total time; r=0.52 for min-to-min counts	NA
Montgomery et al.[159]	3 days preschool-aged children; 7-10 days school-aged children	Total counts; % time in LPA; % time in MVPA; % time in SED	52 girls, 52 boys; 2-7y	PAL_{DLW} (TEE/pREE)	r=0.33 with total PA; r=0.31 with LPA; r=0.22 with MVPA; r=-0.33 with SED	NA
Reilly et al.[163]	Nursery; 40±2 min	SED cut-off of <1100 counts/min	31 girls, 21 boys; 3-4y	DO (CPAF); levels 1-2 considered SED	Sensitivity & specificity for SED was 83% and 82% respectively	NA

Table 3 continued overleaf

Table 3 continued

Study	Measurement protocol	Variables	Participants	Criterion	Validity	Reliability
Actiwatch; 15s and 1min epochs						
Finn et al.[166]	Gross motor activity class; 26.4 ± 7.8min	Mean counts/15s; Mean counts/min	12 girls, 11 boys; 2-5y	DO (CARS)	r=0.33-0.79 for 15s; r=0.15-0.92 for 1 min	NA
Actiwatch; 1min epochs						
Finn and Specker[167]	Childcare setting; 5-6h	Mean counts/3 min	24 girls, 16 boys; 3-4y	DO (CARS)	r=0.03-0.92 (median 0.74)	NA
Kelly et al.[164]	Structured play class, 39-45 min	Mean counts/min for total time; mean min-to-min counts/min	48 girls, 30 boys; 3-4y	DO (CPAF)	r=0.16 (ns) for total time; r=0.55 for min-to-min counts	NA
Lopez-Alarcon et al.[165]	7d	Total counts/day	12 girls, 17 boys; 4-6y	TEE$_{DLW}$	r=0.27 (ns)	NA
Caltrac						
Klesges and Klesges[155]	Unstructured PA at home and in neighbourhood; 7-11h	Total counts/h; total counts/day	13 girls, 15 boys; 2-4y	DO (FATS)	r=0.62-0.95 for hourly; r=0.54 for full day	NA
Klesges et al.[156]	Unstructured free play session in day care centre; 1h	Total counts/h	12 girls, 18 boys; 2-6y	DO (FATS)	r=0.39	NA

Table 3 continued

Study	Measurement protocol	Variables	Participants	Criterion	Validity	Reliability
Caltrac						
Klesges et al.[157]	Caltrac - 1d; DO - unstructured PA at home for 1h, 5d after Caltrac	Not stated	100 girls, 122 boys; 3-6y	DO (SCAN-CAT)	no association found	NA
Mukeshi et al.[158]	Indoor and outdoor play	kcal/h	9 girls, 11 boys; 2-3y	DO (FATS)	r=0.25-0.62 for total kcal/h; r=0.47-0.56 for indoor; r=0.16-0.48 for outdoor	NA
Noland et al.[49]	Unstructured free play	Total counts/h	22 girls, 29 boys; 2-5y	DO (CARS)	r=0.86	NA
LSI						
Klesges et al.[156]	Unstructured free play session in day care centre; 1h	Total counts/h	12 girls, 18 boys; 2-6y	DO (FATS)	r=0.38	NA

Actical = omni-directional accelerometer; **ActiGraph** = uni-axial accelerometer, previously known as the CSA 7164; **Actiwatch** = bi-axial accelerometer; **Caltrac** = uni-axial accelerometer; **CARS** = Children's Activity Rating Scale; **CAT** = Children's Activity Timesampling method of observation; **CPAF** = Children's Physical Activity Form; **DLW** = doubly labelled water; **DO** = direct observation; **FATS** = Fargo Activity Timesampling Survey; **ICC** = Intraclass correlation coefficient; κ = Cohen's kappa statistic; **kcal** = kilocalories; **LPA** = light PA; **LSI** = Large Scale Integrated PA monitor; **MPA** = moderate PA; **MVPA** = moderate-to-vigorous PA; **NA** = not applicable; **ns** = not significant; **PA** = PA; **pREE** = predicted resting energy expenditure; **SCAN** = Study of Children's Activity and Nutrition; **SED** = sedentary activity; **TEE** = total energy expenditure; **VO$_2$** = oxygen consumption; **VPA** = vigorous PA

Accelerometers have several limitations. Their high unit cost potentially limits their use for larger research studies, and their units of measurement (counts) have less intuitive utility than pedometer step counts. These motion sensors are also unable to detect increased energy cost from upper body movement (e.g., digging in a sandpit), load carriage (e.g., pushing a trolley), changes in surfaces or terrain (e.g., walking on soft surfaces), and some types of PA (e.g., swimming, cycling). In fact, Bassett Jr. et al.[168] suggested that accelerometers overestimate the cost of walking and underestimate the cost of many other activities when used in free-living conditions.

In addition, there are a number of contentious issues related to how best to analyse accelerometer data, which make comparison across studies difficult.[169] In particular, the identification of appropriate cut-offs for PA classifications is yet to be determined for children.[170,171] Until a consensus is reached, detailed descriptive accelerometer data should be reported to enable comparison across studies.

Subjective Measures of PA

Traditionally, PA types and patterns in early childhood have been determined by direct observation, a method of observing children and coding PA performed. While systematic observation is sometimes considered to be objective (as a result of stringent observer training and ensuring high levels of inter-observer reliability), this method is nonetheless reliant on human observation, interpretation, and recording of activity, and thus is inherently subjective.[172] By their nature, surveys and questionnaires are also subjective, as they require individuals to report on their own behaviours, or those of another individual (e.g., parental or teacher reports of child activity). Questionnaires and direct observation methods that have been assessed for their accuracy in measuring preschoolers' PA are discussed below.

Direct Observation

Direct observation is often considered a 'criterion' measure for PA in young children due to its practical and comprehensive nature.[57] A search of the literature identified six observation instruments used with preschool-aged children: the CARS,[145] the Observational System for Recording Physical Activity in Children-Preschool Version (OSRAC-P),[173] the Studies of Children's Activity and Nutrition-Children's Activity Time sampling method of observation (SCAN-CAT),[72] the Behaviors of Eating and Activity for Children's Health Evaluation System (BEACHES),[174] the Children's Physical Activity Form (CPAF),[175] and the Fargo Activity Timesampling Survey (FATS).[176]

The CARS has been the direct observation tool most used as a criterion measure for accelerometer (4 studies) and pedometer (3 studies) validation in preschoolers (see Table 3), as well as for assessing the activity levels of this population (see Table 2). The CARS protocol allows for coding of activity in five different categories (resting, low, medium, medium-to-high, vigorous), which may be noted once only within any given minute. This system has been assessed for its practicality and inter-observer reliability over a 12-month period in children (n=491) aged 3-4 years.[145] No child reactivity was recorded for 93.3% of the observations, and high inter-observer agreement (mean [±SD] 84%±10%) was found for the 389 paired observation periods with the younger children. The validation (using VO_2) of this tool was only conducted with older (5-6 year old) children, whereby significant differences in VO_2 were found for each CARS level. Evidence for the between-day and between-year stability of the CARS in preschool children has been shown by DuRant et al.,[177] with a reliability coefficient of r=0.57 for 5.4 days of observation over a 3-year period. Higher levels of reliability were found for the percentage of minutes spent at higher CARS levels (r=0.75 for levels 3-5; r=0.74 for levels 4-5), indicating that high intensity activity may be more stable in this population than sedentary and/or low intensity activity.

A modified version of the CARS, the OSRAC-P[173] was developed with preschool children to allow researchers to capture more detailed contextual information including activity type, location, and social environment. Due to the greater information requirements, a short observation of 5 seconds is followed by a longer recording time of 25 seconds. The OSRAC-P was tested in three preschools, and kappa and category-by-category inter-observer agreement values of greater than 0.80 were found for all categories except group composition (κ=0.79), although wide ranges were found for both PA level and type (κ=0.18-1.00 and 0.50-1.00, respectively). Such variation in observer agreement shows the vulnerability of direct observation methods, with its reliance on accurate researcher observation, interpretation, and recording. No validation of this measure in preschoolers has been conducted. An adapted version of the OSRAC-P, the Observation System for Recording Activity in Preschools (OSRAP; 15 seconds observation, 15 seconds recording) has been successfully used in two studies of preschool children to measure PA,[29,65] however, no reliability nor validity testing of this instrument has been reported with young children.

The SCAN-CAT has been used in one study to assess PA levels in preschool children.[72,157] The SCAN-CAT protocol entails 10 seconds of observation followed by 10 seconds of recording. As well as PA level, information on the physical and social environment is also recorded. No studies were found that reported validity or reliability of this measure in preschool children. In contrast, the BEACHES was widely reported due to its application in the SCAN study,[125-129] as is indicated in Table 2. Stability and inter-observer agreement has been assessed for the BEACHES in 42 children aged 4-8 years.[174] Stable estimates for the measure were achieved with four 60-minute observation sessions in the child's home. Nineteen observation sessions were evaluated for inter-observer reliability, with agreement ranging from 94-99% (median κ=0.71-1.0). This finding was likely due to stringent protocols applied by the researchers, including fortnightly training and review sessions, and frequent reassessment of observer accuracy.

The BEACHES was also evaluated for validity in a separate sample of 19 children aged 4-9 years, using heart rate telemetry as a criterion measurement. Findings showed that heart rate (and calculated EE) increased concurrently with each increase in the five BEACHES activity categories (lying – very active), however, the relationship between the BEACHES and heart rate was not calculated. Furthermore, the use of heart rate in quantifying activity in young children is limited, and heart rate is considered an indicator of EE rather than physical movement (see EE section below). Further work is needed to determine the validity of this instrument using more specific comparison measures.

Heart rate monitoring has also been used to validate the CPAF in children aged 8-10 years.[175] The CPAF involves activity coding in 4 different categories (stationary – no movement, stationary – limb movement, slow trunk movement, rapid trunk movement), that can be noted only once within each minute. In the validation study with school-aged children, progressive increases in CPAF activity level were reflected with increased mean heart rate for seven out of nine activity point categories. A mean correlation of r=0.64 between heart rate and the CPAF was found for all participants (range r=0.26-0.90), and a regression analysis over time revealed that 72% of the variation in heart rate could be accounted for by the CPAF. Average inter-observer reliability for 57 paired observations over 3 years ranged from 96-98%.

The FATS[176] is the only direct observation method that has been validated using an objective measure of PA in preschoolers. Correlations of r=0.78-0.90 with LSI accelerometers were found in the sample of children (n=14) aged 2-4 years. The use of an activity monitor as opposed to indicators of EE as a criterion measure is a novel approach worthy of further investigation when validating observational methods in preschoolers. Interestingly, while not validated for use with children aged less than 5 years, the SCAN-CAT,[157] CARS, [49,161,166,167] and CPAF[162-164] have all been used as 'criterion' measures for the validation of accelerometers in preschool-aged children.

This use of direct observation tools that have not been validated in the research population of interest as 'criterion' measures raises concerns regarding the accuracy of these study findings. At the same time, these studies could be considered as providing evidence for the convergent validity of these direct observation tools, using accelerometers that in most instances have been widely evaluated and validated with young children.

Strengths of direct observation include the ability to gather detailed information on children's activity patterns and types in a variety of settings, including the ability to measure upper body movement. The BEACHES and OSRAC-P in particular allow for the measurement of detailed related information such as the environment, location, and individuals interacting with the child at the time of observation. Direct observation methods do not rely on parents' or teachers' ability to accurately recall physical activities activity of children being studied. Although hand-held devices may be used for recording data in real-time, these are not essential, and no other equipment is necessary for data collection. Lastly, direct observation methodologies are relatively unobtrusive to the child under study. Conversely, direct observation has a number of limitations. As noted earlier, this method is inherently subjective. Children may change their behaviour due to the research procedure. The processes of observer training and data collection are time consuming and thus expensive and so direct observation is not feasible for large scale studies, or for individual data collection over extended periods of time. As well, coding protocols do not allow for continuous recording of activity, which may result in an inability to adequately assess intermittent activities.

Eight studies were found that assessed the validity and/or reliability of PA questionnaires or diaries with preschool-aged children, all of which are outlined in Table 4. In all of these studies, questionnaires or diaries were completed by proxy report, either by the parent or teacher of the child. One study compared accelerometer-determined activity with PA derived from a time activity diary for 9 children aged 4-17 months.[178] Predominant activity (sleeping, eating, quiet playing, active playing) and location (home-inside, home-outside, away from home) were coded by the child's primary caregiver every 30 minutes for ≤4 days, concurrent with accelerometer wear. A moderate association (r=0.42) and low-to-moderate concordance (57-78%) was found between accelerometer and diary measures. High variability of accelerometer counts for the diary activity classifications both between and within individuals likely reduced the strength of these relationships. Interestingly, although this method involved comparatively high participant burden, 100% compliance was achieved.

Three studies used questionnaires that required the proxy reporter to recall specific activity from the previous 3[179,180] to 4 days,[181] during which time accelerometer-determined PA was also measured. Chen et al.[179] found that children whose PA frequency was rated as 'not often' on their 3-day questionnaire had significantly lower accelerometer counts compared with children who were rated as 'very often' active. Moderate associations of r=0.33 for total activity and r=0.53 for MVPA were found for the 3-day checklist of Burdette et al.[180] and the 4-day questionnaire of Harro et al.,[181] respectively. The stronger correlation found in the latter study may be due to the investigation of a specific PA variable (percentage of time in MVPA) as opposed to total daily activity, or as a result of gathering information from both parents and teachers. The Harro et al.[181] study was the only one to take such an approach, which may be worthy of further investigation, as it allowed the researcher to gather information on total daily PA at home, and within ECE and care settings.

Table 4: Validation of proxy-report questionnaires and diaries to assess preschoolers' PA

Study	Questionnaire	Proxy reporter	Participants	Criterion measure	Validity	Reliability
Burdette et al.[180]	Checklist for outdoor play time for the measurement period (3 days); recall of usual outdoor playtime in previous month (min/day)	Parent	107 girls, 143 boys; 2-4y	Tritrac-R3D; 3 days	r=0.33 for checklist; r=0.20 for recall	NA
Chen et al.[179]	Questions on children's PA levels during measurement period	Nursery teacher	9 girls, 12 boys; 3-4y	Actiwatch; EE (Caloriecounter Select II); 3 days	Questionnaire PA categories distinguished between accelerometer PA and Caloriecounter EE categories	NA
Goran et al.[182]	Modifiable activity questionnaire (h/day of PA, sleep, TV watching)	Mother	53 girls, 48 boys; 5.3 ± 0.9y	AEE_{DLW}; 14 days	No significant correlation observed	NA
Harro[181]	Questions on children's PA levels, active transportation, and sedentary behaviours during the measurement period	Parent and teacher	32 girls, 30 boys; 4-8y	Caltrac; HR; 4 days	% time MVPA from questionnaire r=0.53 for Caltrac, r=0.40 for HR	NA
Janz et al.[183]	Netherlands Physical Activity Questionnaire for Young Children (usual PA patterns and preferences)	Parent	113 girls, 91 boys; 4-7y	ActiGraph; 4 days	r=0.33 for total PA; r=0.36 for VPA	ICC=0.70

Table 4 continued overleaf

Table 4 continued

Study	Questionnaire	Proxy reporter	Participants	Criterion measure	Validity	Reliability
Klesges et al.[157]	Energy Balance Questionnaire of the SCAN	Parent	100 girls, 122 boys; 3-6y	DO Caltrac	Maternal reported questions loaded moderately (0.54-0.71) on to a 'general activity' factor	NA
Saris and Binkhorst[184]	Netherlands Physical Activity Questionnaire for Young Children (usual PA patterns and preferences)	Parent/teacher	11 children; 4-6y	Pedometer	Questionnaire PA categories distinguished between different pedometer PA categories	NA
Telama et al.[185]	Questions on average outdoor play, perceived levels of play, child's preferred activities	Parent	278 girls, 294 boys; 3y	N/A	Internal consistency coefficients: r=0.63 for girls; r=0.60 for boys	NA
Tulve et al.[178]	Time activity diary for every 30min over 4d, including PA level and location	Parent	4 girls, 5 boys; 4-17mo	Actical; 4d	r=0.42 for total PA; 70% concordance between accelerometer count and diary PA level tertiles	NA

Burdette et al.[180] also assessed the validity of parental recall of usual outdoor playtime in the previous month with 3-day tri-axial accelerometry. A weaker correlation was observed for the usual activity recall than the 3-day checklist discussed earlier (r=0.20 vs. r=0.33). This indicates that either the usual activity recall questionnaire was not sufficiently accurate, or that the 3-day accelerometry assessment may not be a valid indicator of usual activity. Indeed, a monitoring period of 6 days using ActiGraph accelerometers has been shown as necessary to provide an accurate representation of the usual PA of young children within a preschool setting.[102]

Four other studies also assessed questionnaires that measured 'usual' or 'normal' activity as opposed to actual activity over a given time frame.[182-185] The Netherlands Physical Activity Questionnaire (NPAQ) of usual PA patterns has been investigated in two preschool studies using pedometry[184] and accelerometry.[183] Saris et al.[184] found that the NPAQ could distinguish between children in differing activity categories assessed by pedometry, while Janz et al.[183] found moderate correlations between the NPAQ and accelerometer-determined total PA (r=0.33) and vigorous activity (r=0.36). Although an accepted criterion measure was not used in the study by Saris et al.,[184] the study is worthy of consideration as it provided supporting evidence for the utility of this questionnaire. Telama et al.[185] assessed the internal consistency of a questionnaire on children's average amount of outdoor play, and parental perceptions of their child's activity levels and activity preferences with promising findings (r=0.60-0.63). The questionnaire is yet to be validated against a comparison measure.

One study used EE as assessed with the doubly labelled water method to validate a questionnaire on young children's hours per day of activity, sleep, and TV watching.[182] No significant relationships were found between the measures. It is possible the questionnaire used in the study did not adequately assess children's PA, but it is also important to consider that EE may not be an appropriate 'criterion' measure for tools that attempt to assess PA level and patterns in this population. Another explanation for this finding is that the questionnaire did not assess PA for the same timeframe as the criterion. For example, the studies of Harro et al.[181] and Chen et al.[179] showed evidence for

the validity of activity questionnaires using indicators of EE (heart rate telemetry and the Caloriecounter), when the questionnaire assessed activity for the same period as the criterion assessment. This lack of significant and/or strong relationships between EE and PA measurement tools has also been observed with accelerometers, as discussed earlier.

No standardised questionnaire has been developed and sufficiently evaluated for the assessment of PA in preschool-aged children. Further confounding this problem is a general inability of young children to accurately self-report on duration, frequency, and/or intensity of physical activities performed,[186] and so self-report methodology should not be applied with children aged less than 10 years.[187] Strengths of questionnaires are that they are inexpensive, are not invasive, and can be less time consuming to administer and interpret than objective alternatives of activity assessment. Although more time consuming than questionnaires, detailed information on activity intensity and context can be gained with proxy-report time activity diaries. Further investigation is required to determine the validity of these tools for use with preschool-aged children.

Energy Expenditure

EE is the amount of energy used at rest (REE), during activity (AEE), and over a total period of time (TEE). EE has been considered a separate variable to PA in the current review, as PA is only one factor that contributes to EE. For example, a study of children aged 5 years showed that PA accounted for only 16% (SD 7%) of TEE for the 7 days monitored.[188] One explanation may have been that the participants exhibited extremely low PA levels over the measurement period, however, it is likely there were also other influencing factors. For example, genotype can influence approximately 40% of the variance in REE and LPA or moderate PA (MPA).[189] In a study of white and African-American children, the white children exhibited significantly higher REE, even after adjusting for age, pubertal maturation, and body composition.[190] Conversely, in a study of children from four ethnic groups, ethnicity did not influence REE, but did affect TEE and AEE, boys had a higher REE than girls, and body weight was the best predictor of TEE.[191]

Likewise, a large study of obese and non-obese children showed that while PA was higher in the non-obese children, EE of the obese children was higher than that of the non-obese children.[192] A comparison of heart rate response to exercise in obese and non-obese children found that heart rate was significantly higher in children with increased skinfold thicknesses both during and after exercise.[193]

Given that overweight and obesity are often variables of interest when assessing PA and health outcomes, this confounding effect of weight status can mean that EE will not accurately depict the relationship between activity and body size, and the true effect of PA is likely to be masked. A 4-year longitudinal study of children's body size and REE, AEE, and TEE showed that body size was not related to EE, but instead was related to sex, initial fatness, and parental fatness.[194] One study concluded that AEE should be normalised for fat-free mass to control for the confounding influences of gender, age, and body size on EE calculations.[195] Another study found that, after adjusting for initial body composition, age, ethnicity, gender, and maturational stage, REE, AEE, and TEE did not predict increasing adiposity in children, however, aerobic fitness did.[196] In summary, EE is a complex variable determined by a multitude of factors, and so should not be considered an exact account of PA. It is worth noting that despite this limitation, EE is routinely utilised as a 'criterion' measure for assessing PA measurement tools (see Table 3). Moreover, EE has been used to validate direct observation, which in turn has been used as a 'criterion' measure for motion sensors.

Heart rate monitoring is especially limited as a PA proxy or 'criterion' as it is an indirect approximation of EE that is reliant on the assumption that a linear relationship exists between heart rate and VO_2. Heart rate is sensitive to a number of factors including emotional stress, body position, and digestion.[197,198] At lower levels of activity, these factors may confound the relationship between heart rate and VO_2 and thus provide an inaccurate estimation of PA level. Furthermore, the variety of methods employed to define resting heart rate in children can lead to substantial differences in activity classification when heart rate is extrapolated to PA level.[199]

Issues with PA Assessment in Preschoolers

Further to validity and reliability assessment of potential measurement tools, consideration must be given to the ability of these tools to capture the movement types and patterns unique to preschool children. Particular facets of activity participation in young children that are important to consider are outlined below.

How do Preschool Children Move?

The choice of appropriate PA measurement tools will be influenced by the developmental stages of preschool-aged children and subsequent PA types and patterns that are typical of this population. The social and physical development that occurs during early childhood means that compared to school-aged children, preschoolers participate in activities that require less vertical movement (e.g., ambulation during organised activities) and more omni-directional movement (e.g., rolling and climbing in solitary and pretend play).[200,201] Accordingly, if motion sensors are being used, monitors that are capable of capturing measurement over more than one plane of movement are recommended. Additionally, movement (especially walking) patterns of young children may have more horizontal motion than that exhibited by older children, due to their wider base of support during gait development.[202] As such, motion sensor readings may be dependent on location of the sensor (e.g., hip or back placement).

PA Patterning in Preschoolers

Table 2 shows the studies found that have assessed PA engagement in preschool-aged children. Due to the range of data collection methodologies used across a small number of studies (with small sample sizes), it is not possible to identify clearly the PA characteristics of this population, nor to compare findings across studies. Even so, some interesting patterns in PA can still be found from the literature. For example, there is a general consensus that young boys are more active than young girls. The ability to gather contextual information concurrent with PA quantification to explain this gender difference

would therefore be useful. It also appears that preschool-aged children participate in very little VPA, and exhibit high levels of sedentary behaviour. When children are active, movement is characterised by short bursts of activity, and velocity and movement types can vary considerably.[53,54,203,204] These findings highlight the importance of being able to quantify and categorise PA intensities and sedentary behaviours in young children. Frequent time-sampling (e.g., epochs of 10-15 seconds) with any measure may be especially important, to be able to discern between PA intensities.

Preschoolers and Sedentary Pursuits

Sedentariness is a construct related yet distinct from PA, and is related to health-risk behaviours such as increased consumption of unhealthy foods.[92,205] Inactivity is commonly assessed in terms of screen time exposure (e.g., TV/movie watching, computer use, game console use).[31,206] Two studies have reported the application of an objective measure of TV watching, the TV Allowance™ (Mindmaster Inc., Miami, FL) monitor.[78,207] Robinson et al.[207] successfully used this device to assess TV watching time over 3 weeks with eighty children at risk of overweight/obesity aged 4-7 years. Findings showed that children with a TV in their bedroom watched significantly more TV than children without a bedroom TV (mean [±SD] 29.8±14.2 and 21.4±9.1 hours/week, respectively). Interestingly, parental reports of the amount of child TV viewing were significantly overestimated when no TV was in the child's room, and significantly underestimated when the child had a TV in their bedroom. Similar levels of objectively assessed TV watching time for young boys and girls were reported by Roemmich et al.[78] (mean [±SD] 24.3±9.1 and 23.7±9.0 hours/week, respectively).

Reilly et al.[163] have recently established accelerometer cut-points to enable objective quantification of sedentary behaviour in preschoolers. Amount of sedentary behaviour may be more important to assess than PA levels when investigating relationships between PA and health in preschool-aged children. For example, greater than 2-3 hours daily of inactivity have been associated with increased overweight and obesity in cross-sectional and longitudinal studies of preschool-aged children.[28,30-33,35,70,163] Furthermore, high amounts of

TV viewing (>2 hours daily) has been observed in infants, and this indicator of inactivity has been shown to track into childhood.[208] The relationship of inactivity to health outcomes highlights the importance of using tools that are capable of identifying sedentary behaviour patterns in this population, as an overall measure of total activity may not appropriately describe the PA behaviours that could be related to health.

Future Research

Further investigation of all the motion sensors previously described is required to examine their accuracy and utility in differing settings (e.g., indoors vs. outdoors) and over different periods of time. More work also needs to be done to determine how best to identify cut-off points for PA intensities in young children. The accuracy of pedometers with preschoolers is still yet to be clearly established.

The Yamax SW-200 is the only pedometer that has been assessed for validity with preschool-aged children. The utility of alternative pedometer models for use with preschoolers is yet to be determined. The NL2000 pedometer can collect daily PA data over a maximum of 7 days, and is more accurate than the Yamax DW series in school-aged children walking at slow speeds.[209] Both the Yamax DW/SW series and NL2000 pedometers are unable to capture activity intensities, which may be of particular importance when considering preschool activity and health. The ankle-mounted StepWatch Activity Monitor[210] is the only pedometer that can quantify activity patterns and intensities, collecting data in epochs from 6 seconds to 25.5 minutes, but is yet to be evaluated with preschoolers.

Reactivity to motion sensor use with preschool children is not well understood. It is possible that potential reactivity may be mitigated by pedometer placement at the back of the child, or by increased pedometer exposure, however, these approaches are not well understood. More research is required to understand the effects of age, body size (particularly abdominal adiposity), and velocity differences on pedometer accuracy.

A number of accelerometers have been used with older populations, including: the MINI-LOGGER (Mini Mitter, Sunriver, OR), the ActivPAL (PAL Technologies Ltd., Glasgow, UK), the Actillume actigraph (Ambulatory Monitoring, Inc., Ardsely, NY), the Biotrainer (IM systems, Balitmore, MD), the Kenz accelerometer (Select 2 Model, Nagoya, Japan), and the Tracmor (Philips Research, Eindhoven, the Netherlands).[148]

Whether these accelerometers are reliable and valid for use with children aged less than 5 years is yet to be determined. An updated version of the ActiGraph, the ActiGraph GT1M has not yet been assessed with preschool children. The ActiGraph GT1M uses a digital, solid-state accelerometer rather than the piezo-electric bimorph beam used in the older ActiGraph. Research with adolescent children showed that the ActiGraph GT1M measured approximately 7% higher activity than the original ActiGraph model.[211] It was not clear from the study findings whether the GT1M was more accurate than the older ActiGraph, or whether activity was overestimated using the GT1M. The Actical monitors appear promising for use with preschool children, however, further work needs to be done to assess validity in more free-living situations, over extended periods of time (i.e., >20min), and using alternative criterion measures to VO_2. It would be worthwhile to consider the convergent validity of the Caltrac in indoor and outdoor settings, using an objective comparison measure (e.g., the Actical or ActiGraph accelerometers).

Irrespective of their limitations, questionnaires and surveys are likely to be employed for large epidemiological studies, as they are inexpensive and easy to administer. Where possible, such data should be substantiated using a valid and objective measure of PA in a sub-sample of the population under study. No questionnaire has yet been developed and rigorously assessed for accuracy in measuring the PA levels of preschool children. The real utility of questionnaires may be to establish correlates of activity, and to understand contextual and other factors that may inform PA interventions.

Although direct observation has been commonly employed in PA measurement studies in preschoolers, validation of this methodology with young children is limited. Given that direct observation is purported to be an ideal 'criterion' for PA validation studies with preschoolers, this is unquestionably an area for further investigation and clarification. The use of EE as a 'criterion' measure of PA is also problematic. As no alternative exists, differing approaches to assessing convergent validity, such as using more than one comparison measure, should be considered for their efficacy. If EE is used as a proxy for PA, ideally VO_{2max} should be used, as this has been shown to be the strongest marker of AEE in preschool children.[191] Heart rate telemetry should not be used either as a 'criterion' measure of PA, nor as a proxy for PA measurement. Instead, accelerometry could be used as a comparison measure for assessing convergent validity of other motion sensors and of subjective measures of PA, or it could also be used concurrently with EE methodologies to better understand the validity of PA measurement approaches. Alternatively, direct observation methods using frequent time-sampling (i.e., 10-15 second epochs) could be used simultaneously with accelerometry to provide further evidence for convergent validity, and to gather important contextual information.

To date, measures of association have predominantly been employed to assess the validity of PA measurement tools in preschoolers. It may be useful in future studies to consider instead the strength of agreement between measures, thereby identifying any potential bias that may exist with particular measures.[147] The ideal approach for assessing the utility of activity measurement tools in preschoolers is thus proposed as a combination of accelerometry and either direct observation (with frequent sampling) or EE, and using measures of agreement (rather than association) when considering the data.

Many other methods of measuring human PA have been developed and are yet to be assessed with preschool-aged children. The strengths and weaknesses of some potential measures for use with young children are outlined in Table 5. A detailed critique of these measures is beyond the scope of this review, but rather, the inclusion of Table 5 is to provide the reader with a broad understanding of the various tools available for assessment of movement in young children.

Table 5: Potential measurement tools to assess preschoolers' PA

Tool	Description	Strengths	Limitations
Intelligent Device for Energy Expenditure and Activity (IDEAA) (MiniSun, Fresno, CA)[212]	Small hip mounted microprocessor (200g) with 5 sensors (16x4x4mm) that attach at the chest, feet, and mid-quadriceps. Output signals are transmitted from the sensors to the microprocessor, to provide information on activity type (currently calibrated for 32 activities), gait analysis, and duration, frequency, and intensity of activity.	Accurate in adolescents and adults; objective; 48h data collection; very detailed data collection; have potential for validation studies as a convergence measure	Wires are obtrusive; not calibrated for activities typical of preschoolers; unlikely to be practical or cost effective for larger studies
Partial Pulse Positioning (P^3) (Paric Measurement, Auckland, NZ)[213]	Position tracking system within a defined space of up to 1000 square m. A tag worn by individuals transmits signals to four or more fixed receivers surrounding the defined space, and a central controller calculates tag positioning.	Accurate to within 1cm; objective; operates accurately indoors (unlike GPS); real time data output	Captures information in defined spaces only; initial setup is expensive (requires a central control unit, receivers, software); does not assess static activities that include upper body movement
Uptimer (Gorman ProMed Pty Ltd, VIC, Australia)[214]	Leg-mounted lightweight battery operated unit that measures time spent in upright position (uptime) by activation of one or more mercury tilt switches that are sensitive to the position of the thigh relative to gravity. Data is downloaded to a master unit to determine amount of time in uptime and downtime.	Accurate in adults; objective; simple output that can be easily translated to health promotion messages	Not waterproof; does not assess seated activities that include upper body movement; no indication of activity intensity
Global Positioning System-Personal Acquisition Logger (GPS-PAL) (Enertech Consultants, Campbell, CA)[215]	Lightweight global positioning system (GPS) monitor (280g) designed specifically for use with children. Comprises a central electronic unit and battery pack integrated into clothing, and an antenna worn at the shoulder. GPS technology involves establishing time and location coordinates from three or more satellite signals, and can be used to track movement of an individual.	Accurate in adults and children; objective; frequent time sampling (5sec epochs) for 25-30h; time and location data enable the quantification of movement velocity	Expensive (US$1,000 per unit in 2003); signal interference occurs within concrete/steel frame buildings; accurate to within 2-3m outdoors and 4-5m indoors, so not ideal for use in contained environments; does not assess seated activities that include upper body movement
Infra-Red Beam Counters (IRBCs) (e.g., ONSPOT PC2000)[216]	Transmit an infra-red beam across a designated area. Dual infra-red beam counters register 'counts' when the beam from both the transmitting and receiving units are broken.	Objective; unobtrusive; battery life is approximately 3 months	Not accurate in estimating the number of people in park settings; does not provide a measure of PA, rather movement across a defined space

Conclusions

PA participation likely plays an integral role in the health of young children. Preceding understanding the relationships between PA and health outcomes, it is necessary to establish valid and reliable methods of PA quantification in this population. No consensus yet exists on what the preferred method for PA measurement in preschoolers is, nor is there a best practice approach for data analysis and consideration of differing units across studies. Considerably more research is required in this field.

Chapter 4: Pedometer Accuracy in PA Assessment of Preschool Children

Preface

Considerable gaps in knowledge regarding preschool PA measurement were identified in the preceding chapter. Motion sensor use appears the most preferable option due to objectivity, efficiency, and ease of use. Although accelerometers were the most widely used and recommended monitors, pedometers are nonetheless appealing as they are less expensive than accelerometers, and data collected is easier to analyse and translate to the general public. As noted in Chapter 3, the accuracy of pedometers with preschoolers was still yet to be clearly established. The Yamax SW-200 was the only pedometer that has been assessed for validity with preschool-aged children; however, further critique of these monitors was required prior to their application in PA research. In particular, pedometer placement at the back of the child had not been investigated, and the accuracy of pedometer steps had not been compared with observed steps. Finally, the application of measures of agreement to assess validity rather than correlational approaches currently employed was needed. Accordingly, this chapter serves to investigate these issues and assess the utility of Yamax SW-200 pedometers with preschool-aged children, thereby determining the appropriateness of these monitors for use in future research in this population.

Introduction

Accurate quantification of PA in early childhood is recognised as being fundamentally important for a number of reasons including measuring levels of, and changes in, PA levels, establishing dose-response relationships between PA and health outcomes, allowing effectiveness of interventions to be ascertained, and to identify children at increased health risk because of their physical inactivity. While considered the 'gold-standard' for PA measurement,[57] direct observation can be impractical for epidemiological research as it is time consuming, expensive, and is reliant on observer precision and presence which is often unfeasible. In contrast, accelerometry and pedometry allow for objective and more efficient data collection. While these motion sensors have been used widely in school-aged children to understand total daily PA, limited work has assessed the efficacy of these instruments in younger, preschool-aged children.

Accelerometry is the most commonly used objective approach to monitoring free-living PA in young children, and a variety of accelerometer models have been well validated in this population.[26,66,102,111,153,154,161,162,164,166] Accelerometers are not, however, without limitations. Their cost potentially limits their use for larger research studies and their units of measurement (counts) have less intuitive utility than pedometer step counts or accumulated time spent being active. Consequently, pedometers are often promoted as a preferred alternative to accelerometers for the objective measurement of PA, particularly in youth[217] because of their affordability, reliability, and validity in assessing free-living PA.

The validity and reliability of Yamax Digiwalker SW-200 pedometers (Yamax Inc., Tokyo, Japan) have been demonstrated within a preschool population by Louie et al.[142] and McKee et al.[143] In both studies, the CARS was used concurrently to validate the pedometers during preschool free-play sessions, with significant correlations found between total pedometer counts and CARS scores (r=0.637-0.950, P<0.01). Louie et al.[142] also found no significant step count difference (P>0.05) between pedometers worn on the left and right hips. There remain, however, a number of unanswered questions regarding pedometer use in early childhood populations. For example, no research has

investigated pedometer validity in preschoolers using actual step counts as a criterion measure. Placement of pedometers at the back of the child (where it is not in their direct view) may mitigate any reactivity to pedometer wearing; however, the reliability of pedometers worn at the back has not been established in young children.

The current study was developed to gather more empirical evidence for the accuracy of pedometer use with preschool children and to answer some of the outstanding questions. Specifically, the validity of the Yamax SW-200 Digiwalker pedometer measures compared to direct observation values (using CARS) in free play was assessed. Further, the accuracy and reliability of pedometer readings compared with observed steps across three sites of placement (left hip, right hip, back) and over three pace conditions (slow walk, normal walk, run) in these preschool children were investigated.

Methods

Participants

A convenience sample of thirteen 3-5 year-old children attending the Auckland University of Technology Akoranga Crèche (childcare centre for children aged 0-5 years) was recruited for this study. The sample size required for this study was based on the report that a sample of 8-10 children was adequate to detect significant differences between motion sensor readings,[162] and allowed for 25% attrition. The exclusion criterion was an inability to walk. Parental consent and participant assent were gained for all stages of the study. Ethical approval to conduct the study was granted by the Auckland University of Technology Ethics Committee (Appendices A and B). Ethical guidelines were adhered to at all stages of the study. Prior to use, reliability of all pedometers was assessed by comparing steps accrued by the pedometers for 100 actual steps taken by the principal investigator at a natural walking pace.

Data Collection Procedures

Two approaches were taken to assess the utility of pedometers to accurately quantify PA in preschool children: validity in unstructured free play, and validity and reliability in straight line walking, as detailed below.

Validity in Unstructured Free Play. Participants were observed during unstructured indoor and outdoor free play sessions of 35 minutes duration in the Crèche, while also wearing a sealed Yamax SW-200 Digiwalker pedometer. The pedometer was attached at the hip (at the anterior superior iliac spine) using a purpose-made elastic waistband. Hip placement (left or right) was randomly assigned. The pedometer was placed on the child and set to '0' immediately prior to observation. Upon observation completion and prior to removing the pedometer and belt, the child was asked to stand still while the pedometer reading was recorded.

The CARS[145] was used to record the observed activity of the children. This measure has been validated using indirect calorimetry, is the most commonly used tool for direct observation, and is also considered a criterion measure in the validation of alternative PA assessment tools.[57] The principal investigator and two research assistants completed 10 hours of training on CARS administration over a two-week period. Training involved using the CARS to document PA patterns of preschoolers at a variety of activity levels, followed by group discussions to clarify appropriate coding methodology and related issues. Both actual observation of unstructured free play sessions in early childhood environments, and videotapes of young children participating in a variety of physical activities, were used for training purposes. The CARS method entailed one or more researchers observing a child and recording 1-5 levels of PA for each minute of observation. CARS activity levels were categorized on a Likert scale ranging from 1 (resting) to 5 (strenuous, very high). Any given activity level was coded only once within the minute in which the activity was completed. Minute-by-minute average activity levels were then calculated, and were summed for the entire observation period.

Validity and Reliability in Straight Line Walking. Participants were requested to ambulate along a straight 29 m line at three different speeds ('walk slowly like a snail', 'walk normally', 'run'), while the principal researcher counted actual steps and measured the time taken with a stopwatch. One trial at each gait speed (slow walk, normal walk, run) was completed in a random order. Participants also wore three sealed Yamax SW-200 Digiwalker pedometers secured to an elastic waistband with safety pins at the left hip, right hip, and centre of back. Pedometers were reset to '0' immediately prior to any steps being taken, and accumulated step counts were recorded immediately after ambulation ceased.

Statistical Analyses

All calculations were undertaken using SPSS or STATA and statistical significance was set at α=0.05. Due to the small sample size, medians and ranges were used to describe the location and spread estimates.

Validity in Unstructured Free Play. Total pedometer steps for the observation period were compared with the sum of the minute-by-minute CARS scores. Pedometer steps were regressed against the criterion measure (PA level assessed by the CARS direct observation method) and 95% upper and lower prediction intervals determined.[147] Residual analysis included the plotting of the Studentized residuals against actual pedometer steps with a lowess curve super-imposed.[218] This allows patterns in the residuals that would violate the regression assumptions to be detected. The Studentized residuals were subjected to Shapiro-Wilk's test of normality.[218] To enable comparison with previous research,[142,143] the relationship between PA scores derived from direct observation and pedometry were also assessed using Spearman's correlation coefficients.

Validity and Reliability in Straight Line Walking. Agreement between observed steps and step counts from pedometers worn at each location (left hip, right hip, or back) was assessed using the Bland-Altman method.[146,147] Initially, Bland-Altman plots and associated lowess curves were produced and assessed for each of the three pedometer placement sites against the observed steps at each gait speed to determine whether a combined or sub-grouped analysis was

needed. Assuming negligible correlation between repeated measures, equality in variance between pedometer placement readings for each gait speed (slow walk, normal walk, running) was formally determined using Bartlett's test.[219] Regression analyses were conducted (clustered for repeated measures) to examine the variance in mean difference values between observed steps and each of the pedometer placement readings for each gait speed category. The corresponding 95% limits of agreement were calculated using Student's t critical values.[218] Diagnostics of the analyses mentioned above (i.e., studentised residuals, Shapiro-Wilk's test of normality and Bartlett's test for equality of variance) were checked to determine whether there was any important violation of assumptions regarding data distribution and homoscedasticity.

Results

Thirteen children (7 boys and 6 girls) aged 3.0-4.8 years (median 4.2) participated in the study. Pedometer reliability was high when worn by the principal investigator, with all pedometers counting within ±2% of actual steps taken.

Validity in Unstructured Free Play. Figure 1 shows the linear prediction and 95% prediction intervals for the pedometer data against CARS PA levels for the 35-minute free play session. As can be seen in Figure 1, the 95% prediction interval associated with the pedometer data was wide. For example, at a pedometer count of 1,000 steps, the 95% prediction interval ranges from a CARS activity level of 60.3 to 104.8 (width 44.5). This could also be interpreted as follows. At 1,000 pedometer steps, the 95% prediction interval ranges from an average CARS activity level of 1.7 per minute (resting) to 3.0 per minute (medium to moderate activity), for the 35-minute period. Residual analyses provided no evidence for the violation of assumptions. A significant moderate correlation was observed between direct observation and pedometry (r=0.59, P=0.04).

Figure 1: Linear regression and 95% upper and lower prediction intervals of pedometer step counts in predicting CARS PA level for 35 minutes of unstructured free play
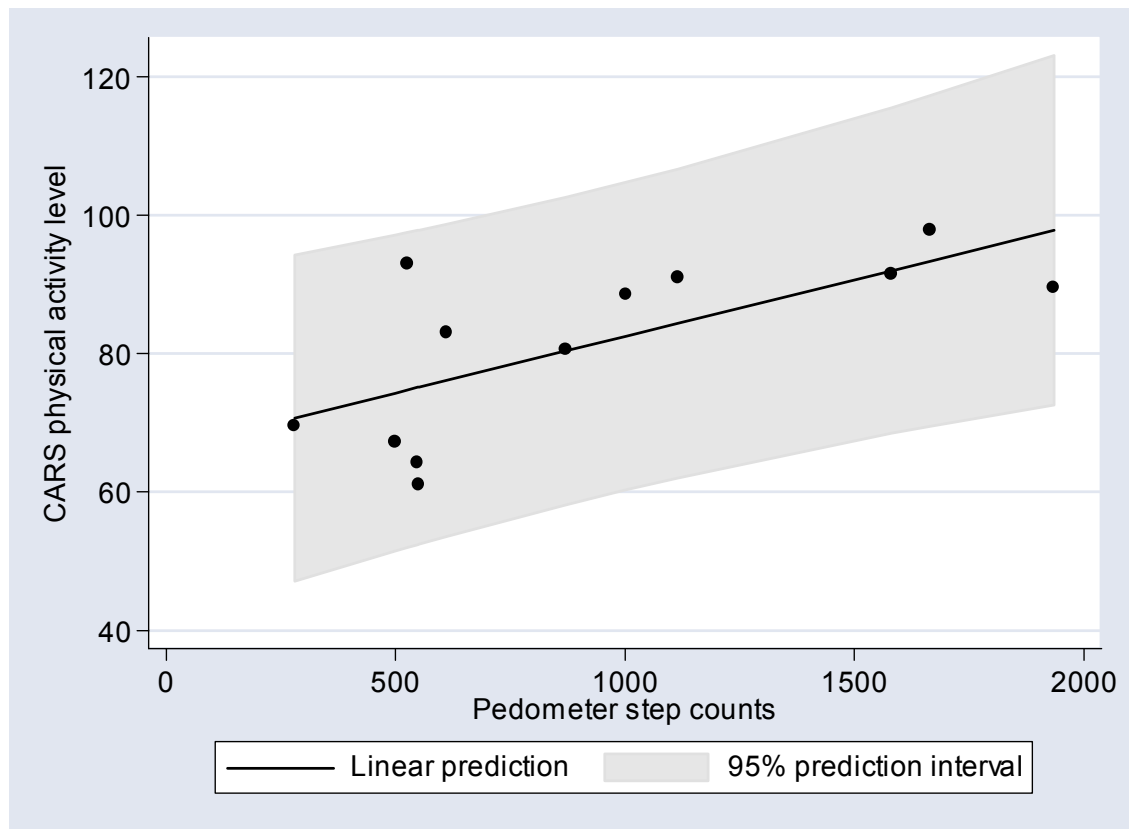
Validity and Reliability in Straight Line Walking. Table 6 shows the median and range (minimum, maximum) of the observed and pedometer step counts worn at the left hip, right hip, and back for each gait speed. Table 7 shows the range of percentage differences between observed steps and pedometers worn at the left hip, right hip, and back. The median (range) velocities for slow walking, normal walking, and running were 0.64 (0.32, 1.04), 0.91 (0.60, 1.38), and 1.81 (1.38, 1.93) m.s^{-1}, respectively.

Table 6: Median and range (minimum, maximum) of the steps observed and recorded from pedometers placed on the left, right and back, partitioned by gait speed

Gait speed	Observed median (min,max)		Left median (min,max)		Right median (min,max)		Back median (min,max)	
Normal	60	(40, 80)	62	(50, 76)	61	(49, 85)	63	(56, 91)
Running	44	(42, 63)	48	(38, 66)	48	(41, 66)	49	(41, 66)
Slow walk	70	(56, 81)	68	(54, 73)	70	(48, 80)	70	(53, 81)
Combined	60	(40, 81)	62	(38, 76)	60	(41, 85)	63	(41, 91)

Table 7: Median and range (minimum, maximum) of relative percentage differences between observed steps and pedometer steps by pedometer site and gait speed

Gait speed	Observed - Left		Observed – Right		Observed – Back	
	% difference median (min,max)		% difference median (min,max)		% difference median (min,max)	
Normal	5	(-5,25)	5	(-7,23)	6	(-10,40)
Running	5	(-10,14)	5	(-10,16)	12	(-13,17)
Slow walk	-8	(-23,20)	-1	(-31,23)	3	(-24,25)
Combined	3	(-23,25)	5	(-31,23)	5	(-24,40)

When investigating paired differences between observed and pedometers step counts, significant heterogeneity was found in the variances of observed-right measurements over gait speed (slow walk, normal walk, running) (Bartlett's test P=0.01) indicating that the objective measurements were dependent on gait speed. While not statistically significant, heterogeneity appeared to be evident in the observed-left (Bartlett's test P=0.11), and observed-back (Bartlett's test P=0.18) measurement differences over gait speed. Lowess curves on the Bland-Altman plots of observed and pedometers step counts failed to show any consistent non-linear pattern over the mean difference step count range (not shown) and clustered regression analysis revealed no significant difference in mean difference values between gait speed categories for the observed–left analyses (P=0.06), observed–right analyses (P=0.42), or the observed–back analyses (P=0.54). This indicates that any systematic bias between observed and pedometers step counts is not dependent on pace. With the small sample size, however, the power to detect significant differences between groups is relatively small. Because of this and the heterogeneous variances, each pedometer site was examined separately over each gait speed.

Figure 2 shows the estimate of the bias and associated 95% limits of agreement for each pedometer site and gait speed relative to the directly observed steps. Limits of agreement were narrowest for running and widest for slow walking, with widths ranging from 15 pedometer steps (for right hip, running) to 44 steps (for right hip, slow walking). The latter can be interpreted as meaning that when an observed step count of 60 is recorded on a slow walking preschool child, in 95% of instances the right hip located pedometer will record a step count between 38 and 82 steps.

Figure 2: 95% limits of agreement for difference between observed step counts and pedometer step counts by ambulatory gait speed, and pedometer placement for preschool children walking in a straight-line over 29m
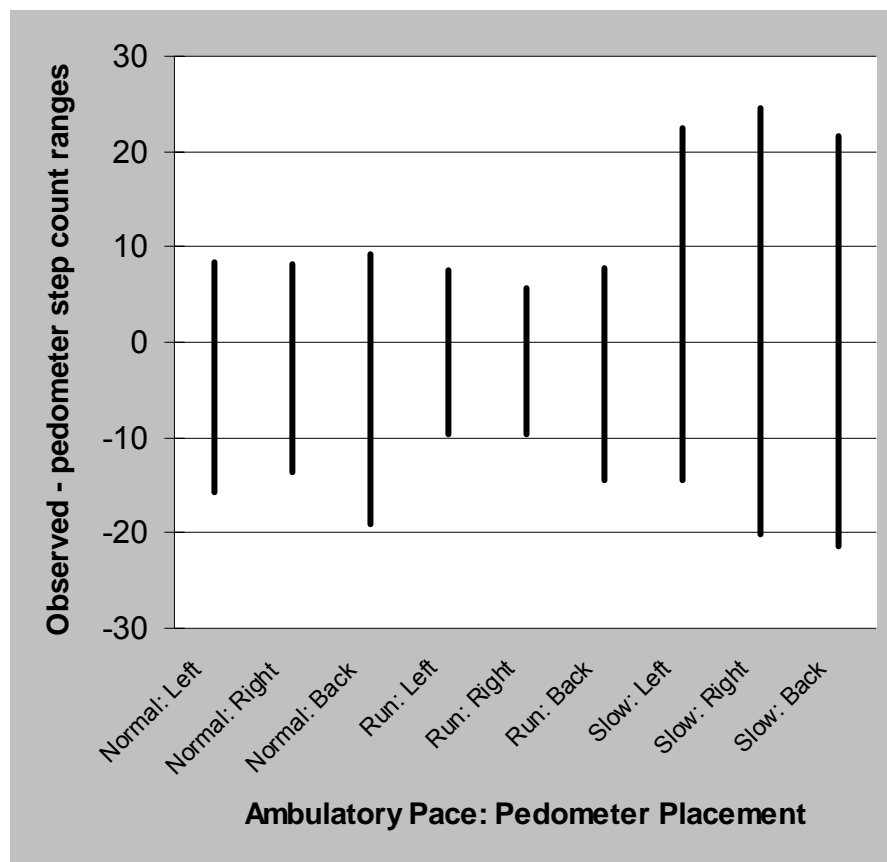
Discussion

The first stage of this study involved assessing the validity of pedometers using direct observation as the criterion measure. Correlations observed in the current study were similar to those found in the larger study of Louie et al.[142] (r=0.59, compared with r=0.64). McKee et al.[143] found stronger correlations than in the present study (r=0.64-0.95), although pedometer data were collected in three minute intervals as opposed to steps accumulated for the entire observation period. This methodology was proposed to account for the sporadic nature of children's activity; however, it is unlikely that the Yamax Digiwalker pedometers would be used in this way for research purposes. Aside from the New Lifestyles NL-2000 pedometer (which is capable of sampling in 24-hour periods), no pedometers have time-sampling capabilities, therefore, collecting data at three-minute intervals would be time consuming and impractical.

Using the approaches of Bland and Altman,[146,147] pedometer accuracy was variable in both stages of the study. In the first stage, the prediction intervals for pedometry were wide. The question thus becomes, does the 95% prediction interval for the pedometer have a width that would be acceptable in the 95% limits of agreement? One approach to answering this question is to try and quantify what would be a meaningful difference in PA using a known standard of measurement. Below we have used the CARS measurement units to understand what a meaningful change in PA for a preschooler might be and related this back to the errors of measurement we have determined for pedometry.

In terms of direct observation, average CARS activity levels of 3-5 per minute might be considered physically active, whereas average levels of 1-2 would be considered inactive, or sedentary. In validating the CARS, significant differences were found between activities conducted at a CARS activity level of 2 (e.g., going down a slide), as compared with activities conducted at a level of 3 (e.g., walking at a moderate gait speed). Therefore, an increase in average activity level per minute by 1 (e.g., from level 2 to level 3) could be considered meaningful.

As reported earlier, the CARS prediction intervals for pedometry at only 1,000 pedometer steps (relative to only 10 minutes brisk walking in adults[220]) ranged from an average of 1.7 to 3.0 per minute (width 1.3) for the 35-minute observation period. Thus, the prediction intervals for these monitors would be considered unacceptable when using changes in CARS activity levels as a criterion for understanding meaningful differences.

It must be noted, however, that a fundamental issue identified in this pilot study was the commonly used and accepted approach of considering direct observation as a criterion measure of PA. The researchers noted a number of limitations inherent with this methodology of quantifying PA, which are outlined individually below:

1. The CARS was developed using EE, not PA, as a criterion. While EE is a consequence of PA participation, this is not a direct measure of activity.

2. Activity coding for the CARS entailed coding activity levels a maximum of once per category during each minute of observation, which may have lead to misrepresentation of activity levels. For example, a child may lie motionless for 3 seconds in a minute (level 1), then run vigorously around a playground for the remaining 57 seconds (level 5). The average coding for this minute would be level 3 ((1+5)/2), when in fact a much greater proportion of activity was spent at a higher level. In other words, if this activity were calculated using second-by-second time sampling, the actual level of activity would be 4.8 (0.05*level 1 + 0.95*level 5). One way to mitigate this is to modify the CARS to match the sampling time frame, as has been done with accelerometers (using 15 second time frames),[166] although this approach would still be problematic when assessing pedometry.

3. While observer training was conducted, direct observation protocols are still inherently subjective, and are reliant on observer accuracy and interpretation of activity.

4. One key purported benefit of using direct observation is the ability to quantify types of activity participated in (e.g., midline crossing). The CARS approach involves estimation of PA level, considering both lower body and upper body movement, but does not provide any descriptive data on the types of physical activities completed.

The second stage of the study was to assess the validity and reliability of pedometers worn at three different sites (left hip, right hip, back) during straight line walking, when compared with step counts from direct observation. Results showed that pedometer variability was significantly dependent on gait speed for the observed-right pedometer measurements. Such variability in pedometer accuracy with walking velocity has been previously reported in adults.[221,222] This phenomenon was also observed between the other pedometer sites and observed measures, however, these interactions were non-significant. It is possible that with a larger sample size, the observed relationships may have reached significance.

Indeed, post-hoc analyses of effect sizes for determining differences between pedometer site placement revealed only small to moderate effect sizes (average Cohen's d between pedometer sites for walking, running, and slow walking were 0.1, 0.2, and 0.5, respectively). Post-hoc calculation of sample size required to achieve a larger effect size of 0.8 using standard definitions of alpha (0.05) and power (80%) revealed a sample of 26 children participating in all pace conditions and wearing pedometers at three sites was necessary (disregarding attrition).

The 95% limits of agreement were slightly less for both left and right pedometer sites than for the back. When data from all three gait speed conditions were combined, the 95% limits width size for back measurements were around 7% wider than the left and right measurement sites. The most important question then becomes, how much variability is acceptable in terms of accurately assessing PA in this population? To date, no studies have utilised pedometry to determine meaningful differences in preschoolers' PA (e.g., in relation to outcomes such as obesity or cardiovascular disease risk), and so it is not possible to answer this question with confidence. Tudor-Locke et al.[223] devised daily step guidelines of 12,000 and 15,000 for school-aged girls and boys, respectively, which were based on a reduced risk of being overweight or obese. As preschool children move differently to school-aged children, these values are unlikely to be relevant to this younger population. An alternative approach to establishing how much variability is acceptable would be to consider the range of percentage differences between the pedometer counts and observed steps. As may be observed in Table 7, the range of percentage differences between observed steps and step counts from pedometers worn at the left hip, right hip, and back were substantial, at 48%, 56%, and 64%, respectively. Considering this variability occurred whilst walking in a straight line over a relatively short distance (29 m), we propose that this amount of variability is not acceptable.

Two explanations are proposed as to why such variability existed in pedometer results during straight line walking. Firstly, movement (especially walking) patterns of young children may have more horizontal motion than that exhibited by older children, due to their wider base of support during gait development.[202]

This may result in different motion sensor readings according to hip placement. It was hypothesised that back placement may be more accurate than placement at either of the hips and may reduce reactivity, as the child cannot see or reach the pedometer. From the current findings, however, we suggest that back placement may result in less accurate data.

Secondly, children may have tampered with the belts on which the pedometers were attached during the straight-line walking test and such moving the belts horizontally or vertically would have changed the site of pedometer measurement. This situation, however, was highly unlikely, given that each individual child was being observed during the test, and the researchers would have discontinued the test had this occurred. Nonetheless, this issue may be relevant for future research, and so is still considered a limitation of pedometry in general. Pedometers could be secured to the child's clothing instead of a belt. Standardisation of measurement procedures could not be achieved with this approach, however, and accuracy would be compromised if children were wearing baggy clothes which could result in measurement 'noise' caused by horizontal as well as lateral motion. The use of elastic belts is ideal, as they are non-intrusive, and provide a level of consistency of pedometer placement, irrespective of type of clothing worn.

Conclusion

Considerable variability was found in the ability of pedometers to accurately predict PA level as assessed with the CARS. Limitations of the CARS direct observation system as a criterion measure for free-living activity have been identified. Consequently, a fundamental issue has been raised as to how best to assess the accuracy of PA measurement tools? Given that the variable of interest is PA rather than EE, it may be that direct observation is the only option. If the CARS (or similar direct observation systems) were to be used for this purpose, the issues identified in this study must be considered, and more frequent time sampling is imperative.

The current study findings indicate that pedometers may not measure steps accurately enough for research purposes with children aged 3-5 years. Pedometer accuracy may be dependent on gait speed, irrespective of site placement, and pedometers may be less accurate when worn at the back, compared with the left or right hip.

It is important to note that these findings pertain only to the distances and activities measured in the current study. Future investigation of whether the 95% limits of agreement for pedometer validity in straight line walking remain essentially unchanged over longer distances (>29 m) would be particularly worthwhile. Of note, these conclusions are in contrast to previous research, which is possibly due to the application of Bland-Altman methods instead of the correlational methods more commonly used in PA measurement research. The former is proposed as a more appropriate approach to assessing the magnitude of the difference between PA measurement tools and to ensure any systematic bias is accounted for. The small sample size limits further definitive exploration, however, the study findings do provide some indicative evidence for patterns to be investigated in future studies.

Practical Implications

- Pedometers may not be sufficiently accurate for research purposes with children aged between 3-5 years, and instead may be better suited for situations where a general idea of preschoolers' accumulated PA is required.
- When using pedometers with children aged 3-5 years, pedometers should be placed at either the left or right hip, rather than at the back of the child.
- If the CARS is used to validate PA measurement tools in preschoolers, the collection of data in timeframes more frequent than the 1-minute protocol should be considered.

Chapter 5: Utility of Accelerometer Thresholds to Classify PA in Preschoolers

Preface

Based on findings from Chapters 3 and 4, accelerometers proved the most appropriate measurement tool of those investigated for measuring PA in young children. As identified in Chapter 3, Actical accelerometers showed promise for use with preschool-aged children; however, further work needed to be done to assess their utility in free-living situations. As noted in Chapter 3, one of the greatest challenges to using accelerometry with young children is the determination of activity intensity using accelerometer thresholds. A variety of approaches were taken to calibrating threshold values in studies reviewed in Chapter 3, resulting in the development of conflicting recommendations and confusion in application and interpretation.

From Chapter 3, we can see that activity types and durations used for threshold calibration are often not representative of young children's usual behaviours, and epoch durations of commonly used accelerometers may not be adequately short to capture the intermittent PA behaviours characteristic of young children. Furthermore, it is likely that the application of a generic approach to classifying PA intensity in young children fails to deal with the substantial developmental differences and movement patterns between individuals in this age group. Consequently, it was possible that the use of any accelerometer count threshold to describe preschoolers' PA in the current context was inappropriate. As such, the study in Chapter 4 was conducted to investigate this hypothesis further and inform PA measurement approaches which could be applied in future studies.

Introduction

Quantification of PA intensity is central to understanding activity prevalence and dose-response relationships between (in)activity and health outcomes in young children.[30,32,70] Using methodologies similar to research with school-aged and adult populations, PA intensity thresholds for accelerometer counts in preschoolers have been determined, allowing the categorisation of sedentary behaviour, LPA, MPA, MVPA, and/or VPA.[154,160,161,163] Adoption of methodologies used with older populations, however, may be inappropriate for the preschool group.

Preschool children have relatively immature kinematics[55] and variable PA characteristics[53,54] compared to their older peers. As such, activity types and sustained durations commonly used in activity monitor calibration with preschoolers (e.g., 3-5 minutes of continuous jogging) are unlikely be replicated in the natural environments of young children, potentially leading to misclassification of MPA and VPA. Furthermore, uniformly determined and applied threshold specifications fail to recognise or account for the substantial individual developmental differences and behavioural patterns associated with this age group. This misclassification is likely to be compounded by the relatively long minimal epoch length at which some accelerometers record activity compared to the highly variable and intermittent behaviours typically associated with preschool children's active play.

To highlight these opined deficiencies and provide empirical evidence for the variability of intensity and duration of PA intensity in preschool children's active play, six children were purposefully selected to reflect diversity in sex, physical maturity, and body size found in children with 'normal' motor development between 3-4 years of age. Typical of validity studies, it was not our intent to recruit a large representative sample,[224] rather to determine patterns common to the diverse sample that are likely to be generalisable to the population of interest.[225] Using second-by-second data gathered from nearly 2 hours of unstructured free-play in outdoor playgrounds, our intention was to provide, for the first time, a description of free-play PA intensity variation and durations for a sample of preschool-aged children. Concordance and agreement in PA level

categorisation using preschooler-specific Actical accelerometer threshold definitions[154] will then be assessed against directly observed (video footage) PA intensity scores derived from a modified CARS. General and child-specific trends will be evaluated and their epidemiologic impact considered.

Methods

Setting and Sample

Outdoor playground local to participant's residence in Auckland, NZ, from February to April 2007. Outdoor settings were chosen to encourage participation in a range of activity intensities with emphasis on MVPA play.[56,62] Six children with 'normal' motor development aged between 3-4 years purposefully selected to reflect diversity in sex, physical maturity and body size.

Design

Prospective, repeated measure, measurement comparison study.

Procedure

Each child was studied on separate occasions. Children were fitted with an Actical accelerometer (Mini-Mitter Co., Inc., Bend, OR); the manufacturers report high between-unit reliability (r=0.97) and minimal variance between these units.[226] Monitors were attached to an elastic belt worn at the waist, with the accelerometer placed laterally above the right iliac crest. The shortest Actical time-sampling frame setting available (15 seconds) was used. Once the accelerometer was fitted and video filming equipment (Sony digital handycam DCR-TRV340E) ready, the child was given unfettered opportunity to engage in unstructured free-play. Play was child-led with parent/caregiver supervision provided for safety purposes. There were no restrictions placed on the participant interacting with other children in the playground (where applicable) or their parent/caregiver. Each participant was videotaped without impeding their natural play behaviours. Video footage was terminated when the child stopped playing, the parent determined play had finished, or 30 minutes had

elapsed. In-built accelerometer event markers were used to enable the synchronization of video footage with accelerometer data. Activation of the event markers was video-recorded at the beginning and end of each measurement, accelerometer data was drawn for the times between each event marker, and video footage data was drawn for the times between each event marker being activated on the footage.

Actical accelerometer data. Accelerometer 15 second epoch data over the duration of play was exported from Actical 2.04 (Mini-Mitter Co., Inc., Bend, OR) into Excel spreadsheets for each child. Count thresholds developed for use with preschool-aged children were adopted and employed to categorize PA intensity as follows: ≤714 counts/15 seconds defined LPA, 715-1410 counts/15 seconds defined MPA, and ≥1411 counts/15 seconds defined VPA.[154]

Directly observed data. Video footage was downloaded and coded in 1-second epochs according to the CARS criteria by a trained and experienced operator.[145] This observation system has been widely used with preschool populations, and has been shown to be reliable for children aged 3-4 years and valid when used with 5-6 year-old children.[145] CARS activity levels range from 1–5 as follows: 1 (stationary/motionless), 2 (stationary/movement of limbs or trunk), 3 (translocation – easy), 4 (translocation – moderate), and 5 (translocation – strenuous).

Second-by-second CARS PA levels were averaged over 15-second epochs corresponding to the accelerometer measurement epochs. Averaged CARS data were then collapsed into categories using the CARS criteria for PA intensities, namely: 1≤ averaged CARS ≤3.0 defined LPA; 3.0< averaged CARS ≤4.0 defined MPA; and 4.0< averaged CARS ≤5.0 defined VPA. A 15-second CARS epoch has previously been successfully implemented in a preschool sample,[161] indicating the adaptability of this measure to differing epoch durations. Behaviour type classifications were drawn from the children's self-selected activities and were coded for each second, similar to the categorisation of activity level.

Statistical analysis

Types and intensities of PA was coded for all available data except instances when the child was not visible in the video footage (e.g. playing hide and seek, crawling through tunnels without viewing portals) and these epochs were excluded. To assess intra-observer reliability, the video footage of two randomly selected participants was recoded and evaluated. Descriptive statistics (minimum, maximum, and median duration) of time spent at each CARS activity level were calculated. Next, 15-second epochs were defined and classified. All 15-second epochs that included unusable data were omitted from subsequent analyses. Classification accuracy between the CARS and accelerometer instruments was determined using percent concordance and Cohen's kappa (κ) statistic.[227] Direction of misclassification was identified using McNemar's test of symmetry[228] under the assumption that the CARS classifications yielded the criterion measure (acknowledging limitations of CARS as a criterion). A sensitivity analysis of the percentage concordance was also undertaken using a range of threshold values for the CARS instrument; namely by letting the threshold between LPA and MPA to range from 2.0 to 3.5 in 0.1 increments, and letting the threshold between MPA and VPA to range from 3.5 to 4.5 in 0.1 increments. All statistical analyses were undertaken using SAS version 9.1 (SAS Institute Inc., Cary, N.C., U.S.A.) and α=0.05 was used to determine statistical significance. Written informed parental consent and participant assent were gained for each child, and ethical approval was gained from the host institution ethics committee (Appendix C).

Results

Descriptive characteristics of the subjects and video footage obtained are provided in Table 8. Overall, 6,540 valid 1-second epochs were captured and intra-observer reliability for 1,994 doubly coded epochs was high (96%). Participants exhibited 32 distinct PA behaviours. Behaviour types most frequently exhibited (based on percentage of total seconds) were walking, climbing up using arms, balancing on bars or ropes without translocation, sitting/standing with trunk/limb movement, running fast, and standing still.

Table 8: Descriptive characteristics of participants and video footage

N = 6	Age (yr)	Sex	Video footage (min)	Unusable data (s)	N 15 s Epochs
1	3.5	m	9.9	26	36
2	4.9	m	23.0	18	90
3	3.0	f	12.1	0	48
4	3.5	f	25.3	69	93
5	4.9	m	19.5	0	78
6	3.5	m	21.2	0	84

Figure 3 depicts box-plots of the duration of exercise (plotted on the logarithmic scale) for each CARS PA level by participant. The minimum duration spent at any one CARS PA level was 1–2 seconds, the median ranged from 1–21 seconds, and the maximum duration at any one CARS level ranged from 5–98 seconds. Children spent 75% of free-play in one intensity level for $\leq$5 seconds, 88% in one PA level for $\leq$10 seconds and 94% in one level for $\leq$15 seconds. Light activities (CARS Level 2) were most commonly associated with longer durations prior to changing intensity. Overall, children participated in CARS levels 1–5 for 7%, 29%, 33% 24%, and 7% of time, respectively.

Figure 3: Box-plots of duration of exercise (plotted on the logarithmic scale) for each CARS PA level by subject (ID=1,..,6)
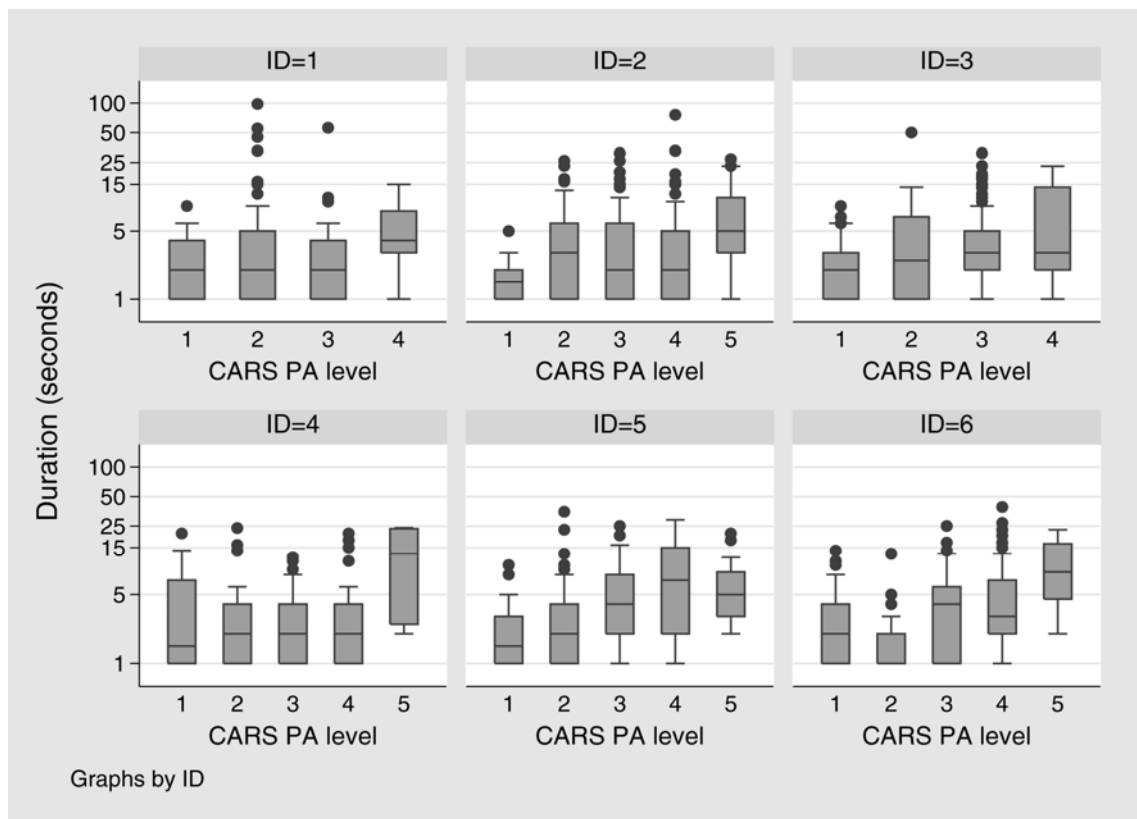
Grouping these 1-second epochs into 15-second epochs, 429 usable epochs were available and the CARS classified 234 (55%) as LPA, 168 (39%) as MPA, and 27 (6%) as VPA. Over these same 15-second epochs, the accelerometer thresholds classified 362 (84%) as LPA, 37 (9%) as MPA and 30 (7%) as VPA. Table 9 shows the relationship between the LPA, MPA, and VPA classifications using the CARS level and accelerometer count thresholds. Overall, 54% of all epochs measured using the Actical accelerometer thresholds for preschoolers[154] were correctly classified, however, 8% of all epochs measured using the accelerometer overestimated CARS by one or more PA levels and 38% underestimated CARS by one or more PA levels; a distribution of discordance that was significantly asymmetrical (McNemar's test P<0.001).

Underestimation of PA level was apparent for directly observed MPA, with 146 (87%) of 168 epochs incorrectly classified as LPA using the accelerometer thresholds, and for VPA, with 16 (59%) of 27 epochs incorrectly classified as LPA or MPA. Concordance for individual participants was moderate and ranged from 44% to 63%, agreement was generally poor (κ ranging from -0.13 to 0.22), and all but one child demonstrated significant asymmetry in their pattern of discordance (see Table 9). Children with significant asymmetry had PA levels classified using the accelerometer thresholds that were systematically underestimated compared with those classified by the CARS. The child without significant asymmetry had no time in CARS classified VPA and modest time in MPA.

Sensitivity analyses of various 15 second average CARS thresholds revealed identical trends (data not shown). Concordance between the instruments was maximised over the range considered by increasing the threshold for LPA to 1≤averaged CARS≤3.5 – a level inconsistent with the description.

Table 9: Number (percentage) of epochs classified as LPA, MPA or VPA using the accelerometer and the CARS for each subject, together with the percentage of concordant observations, the kappa measurement of agreement (κ) and McNemar's test of symmetry p-value

CARS:	LPA			MPA			VPA			%	κ	McNemar's test of symmetry
Actical:	LPA	MPA	VPA	LPA	MPA	VPA	LPA	MPA	VPA	concordance		
ID	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)			p-value
1	20 (95)	0 (0)	1 (5)	11 (92)	0 (0)	1 (8)	1 (33)	0 (0)	2 (67)	61%	0.18	0.007
2	30 (81)	3 (8)	4 (11)	28 (68)	7 (17)	6 (15)	9 (75)	0 (0)	3 (25)	44%	0.11	<0.001
3	24 (65)	9 (24)	4 (11)	9 (82)	2 (18)	0 (0)	-	-	-	56%	-0.13	0.21
4	56 (100)	0 (0)	0 (0)	37 (100)	0 (0)	0 (0)	-	-	-	63%	0.01	<0.001
5	32 (84)	4 (11)	2 (5)	29 (83)	5 (14)	1 (3)	0 (0)	0 (0)	5 (100)	59%	0.22	<0.001
6	45 (98)	1 (2)	0 (0)	31 (100)	0 (0)	0 (0)	0 (0)	6 (86)	1 (14)	60%	0.07	<0.001
Total	206 (88)	17 (7)	11 (5)	146 (87)	14 (8)	8 (5)	10 (37)	6 (22)	11 (41)	57%	0.09	<0.001

CARS = Children's Activity Rating Scale, **ID** = child identification number, **LPA** = light PA, **MPA** = moderate PA, **VPA** = vigorous PA

Discussion

Our results demonstrated considerable misclassification and underestimation of MPA and VPA level when using accelerometer-determined PA intensity thresholds in preschool-aged children engaging in free-play. We propose this is in part due to a lack of consideration of behaviour characteristics specific to this population when calibrating threshold values. Several published accelerometer PA intensity threshold calibration studies with preschoolers based their analysis on PA behaviours such as sustained jogging for 3-5 minutes.[154,160,161] The duration of such behaviours demonstrated within our study, however, is not typical of young children's free play. In fact, in the current study, children spent 75% of free-play in one intensity level for ≤ 5 seconds and the maximum amount of time spent participating in an activity prior to changing activity intensity in our study was 98 seconds. Further complicating this issue is the common use of indirect calorimetry as a gold standard in PA intensity threshold validation studies, which necessitates participation in sustained activities.

Although existing thresholds have been cross-validated in free-living situations, problems still exist. Sirard et al.[161] used a modified version of the CARS to cross-validate Actigraph accelerometer thresholds in preschool settings. The modified protocol allowed for coding of each activity level once within a 15-second epoch, as opposed to only once every minute using the conventional CARS system. Weak-to-moderate correlations of $r=0.46-0.70$ between directly observed and accelerometer-determined PA levels were reported, suggesting that considerable misclassification and likely under-estimation of activity intensity existed between their instrument measurements.

Moreover, the application of correlations in this type of study is also problematic, as systematic bias and the magnitude of the difference between measurement approaches are unaccounted for.[224] Pfeiffer et al.[154] and Pate et al.[160] cross-validated accelerometer thresholds (using Actical and Actigraph accelerometers, respectively) using VO_2 during free play in preschool settings. VO_2 intensity cut-off values were identified based on the ability to use the data to distinguish between a slow walk and brisk walk for MVPA, and brisk walk and jog for VPA (20 mL·kg^{-1} and 30 mL·kg^{-1}·min^{-1}, respectively).

While this approach is more appropriate for use with preschoolers than utilising values previously determined for older children and adults, the reliance on ambulatory behaviours over extended periods of time to categorise PA intensity is still not specific to the population under study. Furthermore, behaviours characteristic of young children's play are unlikely to be demonstrated in such laboratory-based settings. Nevertheless, the Actical accelerometer thresholds had moderate-to-high percent agreement values with VO_2 (73% and 85% for MVPA and VPA, respectively). When accelerometer data were extrapolated to VO_2, however, a tendency to underestimate VO_2 was found. In contrast, Reilly et al.[163] used the CPAF to measure PA intensity of preschoolers wearing Actigraph accelerometers for 100 (SD 17) minutes of free play. A sedentary threshold of 1,100 counts per minute was determined then cross-validated using direct observation in an independent sample of preschool-aged children (sensitivity 83%, specificity 82%). The CPAF did not allow for multiple coding of the same level within a given minute, and so may still result in underestimation of PA intensity.

Calibration and cross-calibration of activity monitors should involve behaviours and durations specific to the population of study. We found that PA characteristics in the 3-4 year-old children in this study were highly variable with 32 types of PA observed, median duration of activity in any one CARS level of 2 seconds and 94% of activities were in one CARS level for ≤15 seconds. Despite the playground setting, the majority of time was spent in sedentary or light behaviour which was interspersed with short bursts of MPA or VPA. These findings are strikingly similar to the previous work of Bailey et al.,[53] whereby the median duration of high intensity PA in school-aged children was 3 seconds, and nearly all VPA (95%) was less than 15 seconds in duration. Although the notion of intermittent play has also been suggested for younger children,[54] the current study is the first to provide conclusive evidence of the sporadic nature of preschoolers' PA.

To our knowledge, only one previous study has investigated the use of differing epoch lengths when measuring PA in preschool-aged children.[229] Klesges et al.[229] favoured time-sampling methodology (10 seconds observation followed by 10 seconds of data recording) over continuous sampling using the FATS. The authors reported an overall correlation of r=0.90 for the two data collection methods for 1 hour of indoor free play with children aged 3-6 years. As noted earlier, however, the use of correlations in such measurement studies is problematic and further investigation of the study findings showed that the 10-second time-sampling method consistently produced lower estimates of PA and higher estimates of inactivity than continuous sampling. Moreover, lower correlations were found for separate PA intensity classifications, ranging from r=0.54 for MPA to r=0.85 for extreme intensity (VPA).

Strengths of the present study include the stringent use of second-by-second video direct observation methodology, with high intra-observer reliability, enabling the collection of a large amount of data and in-depth information on the PA types and durations characteristic of young children. Furthermore, the choice of six children were purposefully selected to reflect diversity in sex, physical maturity, and body size found in children with 'normal' motor development between 3-4 years of age, yet the similarity in results between individuals implies that the findings are likely to be generalisable to the population of interest. By design, however, the study deliberately focused on MVPA, and so the estimates of bias will be inflated if compared to accelerometer-measured and classified 'general day-to-day' activity. We contend that accurately capturing and classifying MPA and VPA in free-play is fundamental to our understanding and monitoring of activity in preschool children. Obtaining reliable measures constitutes one of the major challenges in clinical and epidemiological research.[230]

Although Actical accelerometer manufacturers report high between-monitor reliability, a limitation of the current study is that variance in output between units was not assessed by the researchers prior to fieldwork. Because the same patterns were observed for all individuals and monitors used, the authors are confident that if any between-unit variability did exist, it is likely this was minimal and did not influence the overall study findings.

Accelerometers have been regarded by some as the panacea for objectively quantifying activity. However, simply extrapolating current methodologies and technologies to preschool-aged children resulted in substantial misclassification and underestimation of MPA and VPA in outdoor free-play settings.

Such important misclassifications have considerable epidemiologic consequences in understanding, monitoring, and health promotion of PA in preschool children. As the current methodologies and technologies stand, we believe the application of accelerometer thresholds are of limited value for classifying MPA and VPA in this population. This stance will require reconsideration, however, when technologies evolve such that shorter epoch lengths (i.e., approaching 1 second) can be utilised on all commercially available accelerometers, and thresholds can be developed that are developmentally specific. Until such time, accelerometer count thresholds hold no utility for classifying activity in preschool-aged children and so alternative forms of reporting accelerometer data should be employed.

Chapter 6: Objectively Assessed PA in Preschoolers and their Parents

Preface

Progressively and cumulatively, findings from Chapters 2 to 5 informed the overall thesis direction, culminating in the development of protocols applied for the final studies in Chapters 6 and 7. Chapter 2 confirmed the importance of PA in early childhood and identified the need to further study potential covariates of PA that may be targeted for intervention. In particular, the environmental contexts in which young children move about was identified as important to investigate further in terms of influencing PA and being amenable to change. The information presented in Chapters 3 to 5 critiqued existing PA measurement approaches with preschoolers. Accelerometers were identified as the most appropriate measurement tool to use for the current studies. The use of thresholds to describe young children's PA intensity was found to be inappropriate in Chapter 5, and instead an alternative approach to data consideration was needed.

Therefore, this chapter had two aims: firstly to develop a robust method for reducing accelerometer data to quantify PA in preschool aged children that was not constrained by the limitations of thresholds for estimating PA intensity, and secondly to apply this method in an investigation of potential family-environmental factors that may be related to young children's PA.

Introduction

PA participation in preschool-aged children is important for physical and psychological development[27,82] and is associated with improved bone health,[25] decreased likelihood of exhibiting cardiovascular disease risk factors,[79] and a reduced risk of being overweight or obese.[29] Accurate quantification of preschoolers' activity is imperative to determine activity prevalence and dose-response relationships between activity and health. Accelerometers are well suited for this purpose; they are durable, compact, and tamper-proof, and they provide an objective measure of activity (counts) accumulated within specified epochs, with detailed information on activity dates and times.

No best practice method for accelerometer data treatment has yet been determined for preschool-aged children. Central to this dilemma is the common use of accelerometer count thresholds to define activity intensity, an approach which is problematic with preschoolers for three key reasons, being: activity types and durations used for threshold calibration are often not representative of young children's usual behaviours, which may result in misclassification of activity intensity; epoch durations of commonly used accelerometers may not be adequately short to capture the sporadic behaviours characteristic of young children; and, a blanket approach to classifying PA intensity fails to deal with for the substantial developmental differences and movement patterns between individuals in this age group.[53-55]

To date, a variety of approaches to accelerometer data treatment have been undertaken by researchers, resulting in inconsistent reporting of activity levels, and a general lack of understanding of activity prevalence, patterns, and associates in this population. Determining and understanding the social and environmental factors associated with PA for young children is vital for the development of successful PA interventions and therefore improved long-term health outcomes. Intuitively the immediate family is of primary importance as the young child's attitudes, beliefs, and behaviours are moulded within this unit.

Moreover, preschool children invariably have almost complete reliance on their primary caregivers (usually family), when in their care, for PA opportunities. Parental PA levels[51] and parental encouragement of PA in their preschool-aged child[52] have been linked with objectively measured activity; however these relationships are yet to be convincingly determined using consistent and robust objective PA measurement methodologies.

Using a robust study design, contemporary best-practice epidemiological PA measurement methods, and sophisticated statistical methods, this study presents a novel approach to accelerometer data reduction and application in preschool-aged children. Study aims were to use a multi-level, repeated-measures multivariable modelling approach to assess the relationship between objectively-assessed PA of preschool-aged children and their parents, and investigate potential child, maternal, and paternal factors of PA in preschool-aged children.

Methods

Study Design and Sample

This study investigates families of children aged 2-5 years attending ECE settings in Auckland, NZ, between October 2006 and July 2007.

Recruitment

Families with children aged 2-5 years were invited to participate via eleven ECE settings and networks within Auckland. ECE settings were invited to be involved in recruitment via print- and web-based education journal advertisements, and existing ECE networks. Parents who registered their interest were contacted by the lead author or a research officer. If parents and children remained willing to be involved, they were formally registered with the study and later visited at their home so that written informed parental consent and child assent could be gained. Child assent and PA participation was essential for the family to be eligible for the study. Primary caregivers were required to provide consent and answer the study questionnaires, however, their participation in PA and body

size measurement components of the study was voluntary. All individuals participating in the PA measurement were required to be able to walk. The mother, father, and child triad was recruited where possible (but not other siblings) from two parent families and the primary parent care-giver and child dyad was recruited where possible from single parent families. Ethical approval was gained from the host institution ethics committee (Appendix D). Feedback was provided to participants via email or post on completion of their participation (Appendix E).

Measures and Protocol

PA was measured in 15-second epochs using Actical accelerometers (Mini-Mitter Co., Inc., Bend, OR). The validity of these accelerometers have been assessed using associations with VO_2 in preschool-aged children (r=0.59–0.89), and high between-unit reliability has been determined by the manufacturers (r=0.97).[154,226] Because the research focus was on identifying relationships between physical activity patterns identified in the accelerometer data rather than from the absolute count values, it was not deemed necessary to conduct any further reliability assessment prior to fieldwork. Accelerometers were attached to an elastic belt worn at the waist laterally above the right iliac crest of the child and participating parent(s). Primary caregivers were asked to ensure that their child's and their own accelerometer belts were worn during waking hours for seven consecutive days. A 7-day monitoring protocol has been established as a reliable measure of habitual PA and as an appropriate indicator of weekend versus weekday activity in youth and adults.[231,232]

Height of participating children and parents was assessed to the nearest 0.1 cm using a Portable Height Scale (Mentone Educational Centre, Victoria, Australia) and weight was measured to the nearest 0.1 kg using Seca 770 scales (Protec Solutions Ltd, Wellington, NZ). BMI status for children was determined using International Obesity Task Force criteria[91] and for adults using 25 and 30 kg/m^2 as thresholds for overweight and obesity, respectively. Waist circumference was measured to the nearest 0.1 cm using a Lufkin W606PM tape (Cooper Tools, Apex, NC, US).

Thresholds for high trunk mass were set at 80 and 94 cm for mothers and fathers, respectively,[233] and classification criteria established by Taylor et al.[234] were applied for children. International Society for the Advancement of Kinanthropometry[235] protocols were implemented in all instances. A brief questionnaire was constructed to gather information on participant demographics (including age, ethnicity), and home physical environment details (not used here) (Appendix F).

Procedure

Once written informed parental consent and child assent was obtained then height, weight, and waist circumference measurements were taken and the brief questionnaire was administered. Participants were provided with accelerometers and given training in wearing them and instruction for their use. In an effort to obtain usual PA patterns, participants were encouraged to behave in their normal routines over the following week. A second home visit appointment was made approximately seven days later to collect the accelerometer(s). Participants were free to contact the lead investigator at any time over the 7-day period if they had questions or experienced any difficulties.

Statistical Analyses

Accelerometer data were downloaded using Actical® Version 2.04 (Mini-Mitter Co., Inc., Bend, OR). Custom intervals were set for durations that the accelerometers were worn. Raw data (in 15-second epochs) were exported to Microsoft Office Excel 2003 (Microsoft Corporation, US) and data pertaining to accelerometer wear-time only were extracted for each individual using the custom interval information.

Commonly, accelerometer data are described using one or more of the following: average counts per minute, hour, or day; total counts per day; percentage or minutes per day of sedentary/LPA, MPA, MVPA activity and/or VPA. Because of several contentious issues related to accelerometer data reduction in children[236] and the enormous amount of data collected, a novel two-stage data treatment approach was developed: firstly, for each individual,

the accelerometer data were reduced to average activity rates per second for each day; and secondly, as a group, these average activity rates were related to potential determinants. For each participant, daily average activity rates were conceived as arising exchangeably from some unspecified participant-specific normal distribution. Using these rates to describe PA is substantially different to existing data treatment protocols and mitigates many problems associated with accelerometer data treatment such as defining a 'day', reporting consistent outcome variables, aggregating days of data, and classifying PA intensity.[169]

Accelerometer data reduction. Descriptive statistics, bar-charts, and scatter-plots with super-imposed lowess curves (a nonparametric estimator of the mean function) of accelerometer counts over time for each day were created for individual participants to visually explore the PA patterning within and between days. Although accelerometer counts have been considered to be Poisson distributed, over-dispersion was investigated using a negative binomial distribution (which can be conceived as a gamma mix of Poisson parameters). Recognising the likely serial correlation between consecutive 15-second epochs and non-normal distribution of accelerometer counts, separate GEE methods were employed to estimate daily average activity rates per second for each participant.[237] Because it was considered that accelerometer counts measured in consecutive 15-second epochs are more likely highly correlated than counts measured some time apart, an autoregressive correlation matrix order 1 (AR[1]) was specified and the robust Huber-White sandwich estimate of the variance adopted.

Building a multivariable model to predict child PA. The average activity rates per second for each day for each participant were taken as exchangeable repeated measures from some underlying normal distribution for that participant. As such, GEE methods were used to build a model predicting child PA, except here rates were modelled using a normal distribution, an exchangeable correlation matrix specified, and the robust Huber-White sandwich estimate of the variance adopted. Preliminary univariable analyses were conducted for daily child rates and potential factors. Factors with Wald's p-value≤0.1 in the univariable analyses were then entered into a multivariable model and backward elimination of non-significant terms was conducted until the most parsimonious

multivariable model was found. Residual values of the final model were tested using the Shapiro-Wilk's test for normality and visual assessment of residuals plotted against predicted means, associated lowess curves, and histographs to detect any important violation of the model's assumptions. Statistical significance was set at α=0.05 and analyses were undertaken using SAS version 9.1 (SAS Institute Inc., Cary, NC, US) and Stata SE version 9.2 (StataCorp, TX, US).

Results

Overall 93 families registered for the study and 93 children, 74 mothers, and 22 fathers were enrolled (Figure 4). PA data were collected for 78 children aged 3.9 (range 2.0-5.0) years, 62 mothers aged 36.1 (25.5-44.9) years, and 20 fathers aged 37.8 (29.7-47.1) years. Of the 73 children who attended some form of ECE in the week of assessment, 22 (30%), 25 (34%), and 26 (36%) went for 1-2 days, 3-4 days, and every day, respectively. Further characteristics of participants with PA data are provided in Table 10. No differences existed between boys and girls in age, ethnicity, BMI status, or trunk mass status (all Fisher's exact tests P>0.05).

Accelerometer data reduction. Basic descriptive statistics for the accelerometer measurement including numbers participating, days worn, and hours worn/day are presented for mothers, fathers and children in Table 11. Most followed the study protocol by wearing the accelerometer for 7-days and waking hours. Individual accelerometer count profiles were variable both within and between days (Figure 5). The PA data were highly over-dispersed across all participants, with the lowest estimated dispersion parameter equalling 4.17 (for a child) and the highest equalling 33.60 (for a father), indicating a negative binomial rather than Poisson likelihood function for the GEE models (Table 11).

Figure 4: Participant recruitment flowchart

```
┌─────────────────────────────────────────────┐
│ Families of children aged 3-4 years invited to │
│  participate via 11 Early Childhood Education   │
│              settings & networks                │
│                  n = 688                        │
└─────────────────────────────────────────────┘
         │
         │        ┌──────────────────────────────────────────┐
         │───────▶│  NOT ASSESSED FOR ELIGIBILITY:             │
         │        │  Did not register interest in participating │
         │        │              n = 595                        │
         ▼        └──────────────────────────────────────────┘
┌─────────────────────────────────────────────┐
│        Families assessed for eligibility       │
│                  n = 93                         │
└─────────────────────────────────────────────┘
         ▼
┌─────────────────────────────────────────────┐
│              Total recruited                   │
│  •  Children              n = 93               │
│  •  Mothers               n = 74               │
│  •  Fathers               n = 22               │
└─────────────────────────────────────────────┘
         │
         │        ┌──────────────────────────────────────────────────────┐
         │        │  DATA MISSING:                                          │
         │        │  •  Child withdrawal                      n = 3          │
         │        │  •  Child accelerometer failure           n = 12         │
         │───────▶│  •  Mother accelerometer failure          n = 12         │
         │        │  •  Father accelerometer failure          n = 2          │
         │        │  •  Incomplete questionnaire              n = 5          │
         │        │  •  Mother declined body size measurement  n = 1         │
         ▼        └──────────────────────────────────────────────────────┘
┌─────────────────────────────────────────────┐
│          Data available for analysis:          │
│  •  Child physical activity      n = 78        │
│  •  Maternal physical activity   n = 62        │
│  •  Paternal physical activity   n = 20        │
│  •  Socio-demographic            n = 88-93     │
│  •  Child body size              n = 90        │
│  •  Maternal body size           n = 73        │
│  •  Paternal body size           n = 22        │
└─────────────────────────────────────────────┘
```

Table 10: Characteristics of children with PA measurement and their mothers and fathers

Characteristic	*n*	(%)
Children		
Sex		
Male	37	(47)
Female	41	(53)
Ethnicity		
NZ European	65	(83)
Maori	5	(6)
Chinese	3	(4)
Other	5	(6)
BMI status		
Underweight or normal weight	56	(72)
Overweight	18	(23)
Obese	4	(5)
Trunk mass status		
Low or normal	63	(81)
High	15	(19)
Mothers		
Age (y)		
25-29	2	(3)
30-34	11	(14)
35-39	19	(24)
40-50	6	(8)
Unknown	42	(53)
BMI status		
Underweight or normal weight	46	(59)
Overweight	20	(26)
Obese	7	(9)
Unknown	5	(6)
Trunk mass status		
Low or normal	43	(55)
High	30	(38)
Unknown	5	(6)
Fathers		
Age (y)		
25-29	1	(1)
30-34	3	(4)
35-39	4	(5)
40-50	3	(4)
Unknown	69	(86)
BMI status		
Underweight or normal weight	6	(8)
Overweight	10	(13)
Obese	6	(8)
Unknown	56	(72)
Trunk mass status		
Low or normal	13	(17)
High	9	(12)
Unknown	56	(72)

When implementing negative binomial GEE models for each individual, average activity rates per second for each day (estimated on the natural logarithmic scale) ranged between 0.88 and 2.45 for all children with median 1.75 and the AR(1) estimate of serial correlation ranged between 0.29 and 0.76 with median 0.58. This implies that the median value of the estimated average accelerometer count per minute for children equals $exp(1.75)\times60 = 345.3$ and that there is a moderate (and meaningful) correlation between accelerometer counts made between successive epochs. These estimates and the results for mothers and fathers are also presented in Table 11. Estimated average activity rate variation between individuals was higher than the within individuals (0.62 vs. 0.11, 1.19 vs. 0.30, and 1.82 vs. 0.32, for children, mothers, and fathers respectively).

Figure 5: Example of PA data collected for a child
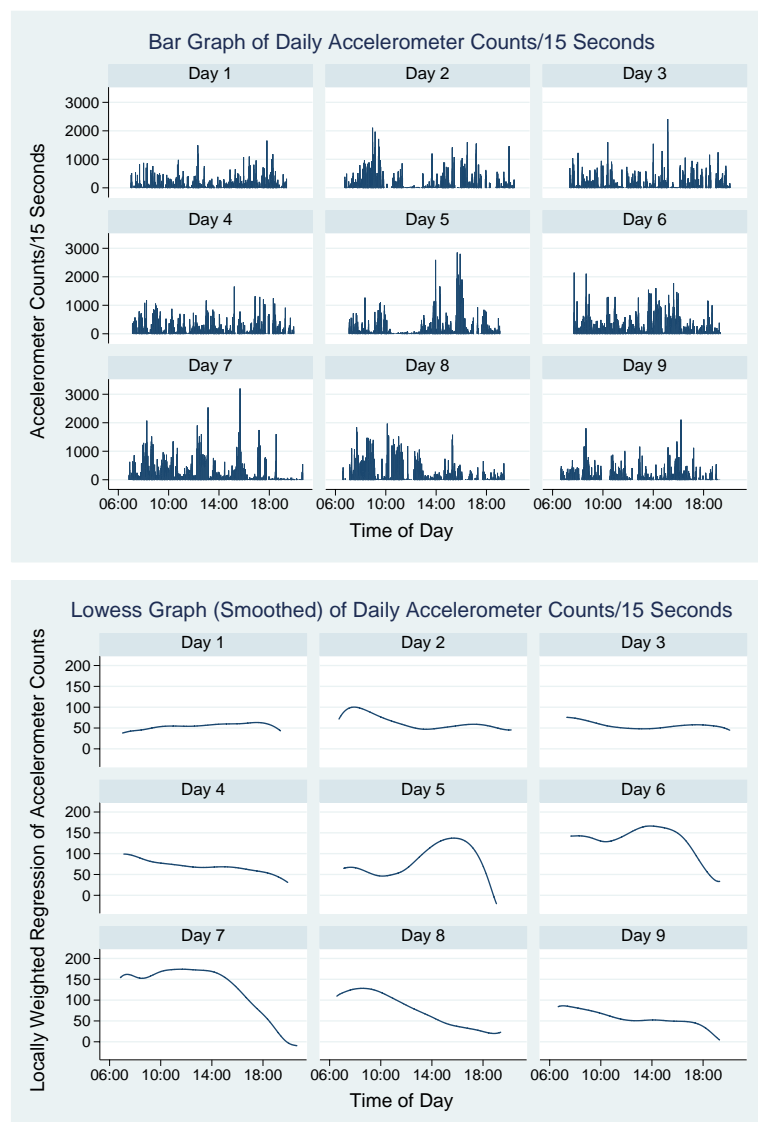
Table 11: Accelerometer measured PA characteristics for children, mothers, and fathers together with a summary of the negative binomial GEE results

	Children (n=78)		Mothers (n=62)		Fathers (n=20)	
	Median	(Range)	Median	(Range)	Median	(Range)
Days worn	7	(1-9)	7	(1-9)	6.5	(5-9)
Hours worn/day	11.1	(2.4-17.8)	13.6	(3.1-21.0)	14.0	(5.9-17.6)
Dispersion parameter	9.95	(4.17-20.18)	13.88	(6.50-25.89)	16.39	(5.86-33.60)
Autoregressive correlation AR(1)	0.58	(0.29-0.76)	0.68	(0.37-0.93)	0.64	(0.43-0.88)
Average activity rate per second for each day[a]	1.75	(0.88-2.45)	1.16	(0.34-2.19)	1.28	(0.45-2.46)

[a]Activity rates are presented on the natural logarithmic scale.

Building a multivariable model to predict child PA. In the preliminary univariable GEE analyses of estimated average activity rates, a significant positive linear relationship was identified between maternal and child rates, and maternal and paternal rates (Table 12). Because of the small number of fathers with PA data and collinearity of maternal and paternal rates within families (data not shown), maternal and paternal rates were combined to form an overall parental rate, thereby improving model stability and statistical power. For days where both mothers and fathers rates were available with families, then the parental rate was defined to be their average. For all other days within families, non-missing mother or father rates were used to define the parental rate. If both mother and father rates were missing then the parental rate was also defined as missing. Results from the preliminary univariable GEE analyses relating this parental rate against the child rates also yielded a significant positive linear relationship (see Table 12).

Table 12: Number of subjects (n), the available data (Obs), together with mean and associated 95% confidence intervals (95% CI) of coefficient estimates from GEE regressions of average rate estimates per second of accelerometer measured PA for mother against child (treated as the dependent), father against child, mother against father, and the parental rates (combined mother and father rates) against child rates

GEE regressions	n (Obs)	Mean	(95% CI)	P-value
Mother against child	61 (367)	0.08	(0.01, 0.15)	0.02
Father against child	19 (113)	0.12	(-0.01, 0.24)	0.06
Mother against father	12 (71)	0.26	(0.12, 0.40)	0.01
Parental against child	68 (413)	0.09	(0.02, 0.16)	0.01

Table 13 provides the GEE results for children's estimated average activity rates and other potential covariates. Two covariates (child age, father age) yielded a Wald's p-value≤0.10 and so were entered into the multivariable model along with the parental rates. After backward elimination, the final parsimonious multivariable model included child's age and parental rates (Table 13). The within-child rate exchangeable correlation estimate equalled 0.41. Taking child age into account, the mean slope coefficient for parental rate was 0.09 (95% CI 0.03, 0.16). This can be interpreted as for every 1 unit increase in parental average activity rate (estimated on the natural logarithmic scale), children's rate will increase on average by 0.09. The Shapiro-Wilk's test of residuals found no evidence to reject the normal assumption, and no pattern or heterogeneity in the residuals was found.

Table 13: Number of subjects (n), the available data (Obs), together with mean and associated 95% confidence intervals (95% CI) of coefficient estimates from univariable and multivariable GEE regressions of children's average rate estimates per second of accelerometer measured PA for considered predictor variable

		Child rate		
	n (Obs)	Mean	(95% CI)	*P*-value
Univariable analyses				
Child				
Age	78 (484)	0.12	(0.02, 0.21)	0.02
Sex	78 (484)			0.13
Male		reference		
Female		-0.11	(-0.25, 0.03)	
BMI status	78 (484)			0.49
Underweight or normal weight		reference		
Overweight		-0.01	(-0.17, 0.14)	
Obese		-0.27	(-0.73, 0.18)	
Trunk mass status	78 (484)			0.23
Low or normal		reference		
High		-0.13	(-0.33, 0.08)	
Day	78 (484)			0.77
Weekday		reference		
Weekend day		0.01	(-0.07, 0.09)	
Mother				
Age	78 (484)			0.52
25-29		reference		
30-34		-0.11	(-0.29, 0.06)	
35-39		-0.02	(-0.15, 0.11)	
40-50		0.16	(-0.09, 0.41)	
Unknown		0.01	(-0.10, 0.11)	
BMI status	78 (484)			0.33
Underweight or normal weight		Reference		
Overweight		0.04	(-0.13, 0.21)	
Obese		-0.16	(-0.41, 0.09)	
Unknown		-0.23	(-0.58, 0.13)	
Trunk mass status	78 (484)			0.20
Low or normal		reference		
High		-0.09	(-0.24, 0.05)	
Unknown		-0.26	(-0.62, 0.10)	
Father				
Age	78 (484)			0.01
25-29		reference		
30-34		-0.16	(-0.23, -0.09)	
35-39		0.07	(-0.07, 0.22)	
40-50		-0.11	(-0.76, 0.54)	
Unknown		0.01	(-0.07, 0.08)	
BMI status	78 (484)			0.49
Underweight or normal weight		reference		
Overweight		0.24	(-0.13, 0.60)	
Obese		-0.01	(-0.44, 0.43)	
Unknown		0.13	(-0.18, 0.44)	
Trunk mass status	78 (484)			0.94
Low or normal		reference		
High		0.01	(-0.33, 0.34)	
Unknown		0.03	(-0.17, 0.24)	
Final multivariable model				
Parent rate, Child age	68 (413)			0.01
Parent rate		0.09	(0.03, 0.16)	0.01
Child age		0.11	(0.01, 0.21)	0.03

Discussion

This is the first study to use a multi-level, repeated-measures multivariable modelling approach to investigate relationships between objectively-assessed activity patterns in preschool-aged children and potential covariates. It is also the first to attempt to mitigate issues related to the reduction of accelerometer data by calculating daily PA rates for children and their parents. Key findings were that child age and parental rate were positively associated with child rate. The only other study to objectively assess PA of parents and their preschool-aged children reported that children of two active parents were 5.8 times more likely to be active as children of two inactive parents.[51] We hypothesize that this relationship is not solely due to parental role modelling, but also increased encouragement and facilitation of children's PA when parents themselves are more active. This study adds objective and robust evidence for the relationship between parental and child activity patterns, which can be incorporated into PA intervention design and promotion.

Concordant with previous research,[110,111] activity rate was independently and positively associated with child age in our sample of preschool-aged children. Whether this was an actual increase in PA behaviours with age or the result of other moderating factors (e.g., physical development, ambulatory kinematics) influencing accelerometer quantification of PA in this age group is debatable. Because this relationship has been replicated using EE[191] and pedometry,[64] it is plausible that older preschool children are indeed more active than their younger peers. Given that PA tracks from early to late preschool years,[58,111] and because a decline in PA occurs during older childhood and adolescence,[238] it is nonetheless essential that PA is encouraged in young children to establish higher PA patterns and encourage prolonged participation in PA.

No other associations were observed for child rate and hypothesized child covariates. The lack of significant association between child rate and sex was unexpected, as numerous studies using various PA measurement protocols have reported that preschool-aged boys are more active than their female counterparts.[25,27,64,66,131]

Our data showed that females had rates, on average, -0.11 (95% CI -0.25, 0.03, P=0.13) less than males. While non-significant, the effect size was still as large as 'age' or 'parental rates'. We propose this non-significant finding was likely due to participant numbers limiting statistical power to detect a significant difference.

In agreement with previous research,[29] the estimated effect between child rate and body size was negative, albeit this was non-significant. Again, we contend that limited participant numbers reduced the statistical power required to find a significant difference. Child rate did not differ between weekdays and weekend days. Inconclusive findings have been previously reported, with a 3-day accelerometer study showing increased light activity in weekends but similar patterns in moderate intensity PA between weekday and weekend days.[86] Either the differences found between individual routines and ECE attendance in our study meant that at a group level, there was an inability to detect differences between weekday and weekend day activity, or there was no real difference between PA on weekdays and weekend days.

Study Strengths and Limitations

There are a number of contentious issues related to how best to analyse accelerometer data,[169] particularly considering appropriate thresholds for PA classifications for children.[171] In their critique of accelerometer data reduction in children, Freedson, Pober, and Janz[236] highlighted the inadequacies of existing approaches and recommended using alternative data treatment using raw counts to determine an activity pattern and characterise activity behaviour. The approach to data reduction outlined in this study provides a solution to many of the problems researchers face when dealing with preschool accelerometer data. We undertook rigorous statistical treatment of accelerometer data using appropriate distributional functions, correlation matrices, and robust estimates of variance exploiting contemporary longitudinal methods. Thorough distributional and residual checks were undertaken to ensure the methods applied and assumptions made were appropriate.

Ideally, all analyses would have been conducted simultaneously, but the enormity of data collected simply made this unfeasible (for example, using median values, one child alone with 7 days of accelerometry for 11.1 hours per day would provide 18,648 data points). It is also important to note that although robust statistical procedures were applied with the accelerometer data, accelerometers themselves are not without limitations. In particular, PA from upper extremity movements, load carriage, and gradient changes could not be assessed, and PA from behaviours such as cycling may have been underestimated.[168]

Our sample were diverse and highly compliant - most participants completed the study protocol, providing detailed PA profiles. Our statistical analyses were hampered by a small sample size, in particular low parental (especially paternal) involvement. Although all but two families were 2-parent families, enrolling fathers in this study was difficult. As well, there was a possible selection bias, given that only 14% of the families invited registered their interest in participating in the study. Our findings show that investigating associates of preschoolers' PA at the family level is important, yet the practicalities of encouraging familial participation pose a considerable challenge to researchers in this field. Ideally, data would have also been gathered over more days and for all waking hours on every day, however, this is unrealistic in such a general population study.

Conclusion

Parental activity rate and child age were independently and significantly associated with child activity rate in the preschoolers in this study. Parental involvement in preschool PA interventions may be most efficacious in improving activity levels of young children, and are likely to have a two-fold benefit; increased PA in parents, and increased PA in children resulting directly from PA intervention and indirectly through increased parental PA. Younger preschool children may benefit more from increased activity and the establishment of activity patterns to mitigate future declines in PA. Accelerometer data can be successfully reduced to individual average activity rates to mitigate current issues related to PA quantification using accelerometers.

Practical Implications

- Calculating PA 'rates' reduces problems with accelerometer data treatment and allows for consistent reporting across studies.
- Encouraging parental participation in PA interventions for preschoolers may be beneficial.
- Younger preschool children may benefit from PA intervention.

Chapter 7: Body size, physical activity and television exposure in preschoolers

Preface

In Chapter 6, accelerometer data were successfully reduced to individual average activity rates to describe the PA of preschool-aged children. Findings from Chapter 6 indicated that the family environment in which a child exists may influence their PA levels, whereby parental PA was associated with that of their child. The calculation of activity rates to quantify PA precluded us from investigating the amount of inactivity, or sedentary behaviours exhibited by these children. As identified in Chapter 2, assessment of inactivity (as opposed to low/reduced PA), appears important in terms of identifying factors related to increased body size in children. As such, further work was required to understand the effect of PA and inactivity on the body size of young children. Consequently, Chapter 7 seeks to explore the associations between young children's body size with PA and TV exposure (considered an indicator of sedentary behaviour), while also taking into account potential demographic factors.

Introduction

The growing preschool-age child obesity epidemic in the developed and developing world represents a substantial health burden worldwide.[38,239] Research evidence now indicates that obesity prevention may be the most efficacious solution to the problem.[240] PA is fundamental to obesity prevention and treatment in preschoolers, and is essential for physical and psychological health and development.[29,86,240-242] Conversely, inactivity, often classified using sedentary behaviours such as TV watching time, has been consistently linked with increased body size in young children.[28,30-33,35,70,163] Of concern, US data show that a high proportion of preschool-aged children exceed recommended TV-watching guidelines,[241] a considerable amount of children start watching TV in infancy, and TV watching behaviours track throughout childhood.[208,243] Sedentary behaviours may have separate and independent negative effects from the benefits of PA on human physiology and body fatness,[244] indicating that PA and inactivity should be considered as individual constructs when investigating factors related to body size. While PA promotion (and inactivity reduction) within families, schools, and communities is thus recommended to help combat what is considered an obesity epidemic,[46,47] efficacious PA interventions remain wanting for the general preschool population.

Although BMI is commonly employed to describe body size in young children, waist circumference (WC) measurement may be important to measure instead of, or in conjunction with, BMI. High WC is related to increased risk of cardiovascular risk factors in children,[245] and adult research has shown this may be a better indicator of health status than BMI alone.[246] Furthermore, although BMI is increasing in preschool populations, there is evidence that WC may be increasing to an even greater extent.[247] Even so, WC is infrequently reported in preschool PA and inactivity literature.

A comprehensive understanding of the complex relationships between BMI, WC, inactivity, and PA are needed to inform effective intervention development. A fundamental barrier to this is the current absence of a best practice approach for objectively quantifying preschoolers' PA. Although accelerometers are the objective measurement tool most commonly employed with preschool populations, no consensus yet exists for appropriate treatment of accelerometer data. In particular, the application of accelerometer count thresholds is disputed due to behaviours uncharacteristic of young children having been used to calibrate threshold values, and epochs being of insufficient duration to obtain information on intermittent behaviours. As well, the considerable individual differences in physical and motor development in the preschool years (and resulting child behaviours and instrument readings) makes the use of count thresholds likely inappropriate.[53-55] Indeed, a critique of accelerometer data reduction with children concluded that until a best practice approach is identified, raw accelerometer counts should be used to determine activity patterns and describe activity behaviours.[236]

As part of a larger family-level project to develop a protocol for accelerometer data reduction with preschoolers and their parents (described in Chapter 6), we also assessed the TV exposure of preschool-aged children using number of TV sets in the household, presence of TV in the child's bedroom, and average TV/movie watching hours during weekdays and weekend days. Body size was determined using WC and BMI, and relationships between child body size, PA, and TV exposure were estimated using regression methods.

Methods

Study Design and Recruitment

This study explored relationships between body size, PA, and TV exposure in children aged 2-5 years in Auckland, NZ, between October 2006 and July 2007. Letters inviting participation in the study were sent to parents/primary caregivers of children aged 2-5 through ECE settings and networks in Auckland. Upon registering their interest, parents were contacted by a member of the research team to explain the study further. If parents agreed to their child participating in

the study, they were formally registered and then visited at their home at a mutually agreeable time to gather parental consent and child assent, and administer study measures. The accelerometer protocol applied meant that children were required to be able to walk to be eligible for the study. Ethical approval was gained from the host institution ethics committee.

Measures and Protocol

Detailed study protocols have been reported previously (Chapter 6). Briefly, children's and parents' (where possible) height was assessed to the nearest 0.1 cm using a Portable Height Scale (Mentone Educational Centre, Victoria, Australia) and weight to the nearest 0.1 kg using Seca 770 scales (Protec Solutions Ltd, Wellington, NZ). International Obesity Task Force criteria[91] was used to classify BMI status for children, and 25 and 30 kg/m^2 as overweight and obesity thresholds, respectively. WC was measured to the nearest 0.1 cm using a Lufkin W606PM tape (Cooper Tools, Apex, NC, USA) and classification criteria established by Taylor et al.[234] were applied for children. Thresholds of 80 and 94 cm were used for high trunk mass in mothers and fathers, respectively.[233] Participants were provided with an Actical accelerometer (Mini-Mitter Co., Inc., Bend, OR) on an elastic belt, set to collect data in 15-second epochs. Parents were asked to place the belt at the hip of their child with the accelerometer above the right iliac crest at the beginning of every day and to remove it prior to the child going to bed in the evening, for seven consecutive days. A questionnaire designed specifically for the study was used to gather information on child demographics, sedentary behaviours, and the child's home environment. Families were re-visited approximately seven days later to collect the accelerometer.

Statistical Analyses

Due to small participant numbers, binary classifications of child BMI and WC were derived. This meant collapsing the BMI classifications of overweight and obese together to give an overall measure of being overweight or obese, as compared with being underweight or normal weight. The Taylor et al.[234] criteria for waist circumference is a binary measure, with children being classified as

having either a low/normal or high waist circumference. In contrast with existing approaches that consider either BMI or WC, predictors of BMI and WC were simultaneously investigated in a single binomial GEE model. Although both variables are considered indicators of body size, each was deemed important to consider simultaneously in analyses because of their differing prevalence trends in children, variance in relationships with health outcomes, and also because of their collinearity. An exchangeable correlation structure between BMI and WC status was used, and the robust Huber-White sandwich estimator specified. Factors with $P \leq 0.10$ from univariable analyses were then added to a multivariable GEE model to predict child body size. Backward elimination of non-significant factors was conducted until the most parsimonious multivariable model was found. Residual values of the final model were tested for normal distribution using the Shapiro-Wilk test for normality and visual analysis of residuals plotted against the predicted means, associated lowess curves, and histographs. To test for the appropriateness of this method, simple logistic regression analyses were also conducted separately for BMI or WC as the outcome measure of body size.

A detailed description of the approach taken to accelerometer data reduction has been reported earlier (Chapter 6). In short, raw accelerometer data were downloaded using Actical® Version 2.04 (Mini-Mitter Co., Inc., Bend, OR), and data pertaining to wear-time only were extracted. Individual accelerometer data were reduced to daily average activity rates per second for individuals derived from negative binomial GEE methods with autoregressive first-order correlation structures. These activity rates are considered exchangeable repeated measures from an underlying normal distribution for each individual. The mean of these daily average rates was calculated to provide a PA measure that approximated the underlying PA characteristic for each individual. Associations between PA and TV exposure were assessed using simple linear regression.

Statistical significance was set at $\alpha = 0.05$ and analyses were undertaken using Stata SE version 9.2 (StataCorp, TX, USA) and SAS version 9.1 (SAS Institute Inc., Cary, NC, US).

Results

Overall, 688 families received invitation letters via eleven ECE settings. Of these, 93 registered their interest and all were eligible so were enrolled in the study, and a total of 80 children, 73 mothers, and 22 fathers completed the body size measurement protocol. Children were aged 2-5 years (median 4.0), and were predominantly NZ European (84%, Maori 6%, Chinese 4%, Other 6%). No significant differences were found between boys and girls in age, ethnicity, BMI status, or trunk mass status (all Fisher's exact tests p>0.05). Using BMI, four children, seven mothers, and six fathers were classified as obese. Child BMI status and child WC status were associated with each other (Φ=0.20).

Only two children had a TV in their bedroom; the insufficient numbers in this category meant that the presence of a bedroom TV could not be considered in the statistical analyses. All households owned at least one TV. Of the 67 children with complete questionnaire data, a majority watched less than 2 hours of TV/movies during weekdays (n=52, 78%) and weekend days (n=42, 62%). Moderate concordance (61%) and fair agreement (κ=0.39) was found between average daily TV/movie watching on weekdays and weekend days. No significant asymmetry was found in the relationship between TV/movie watching on weekdays and weekend days (McNemar's test of symmetry P=0.08).

Three children did not wear the accelerometer belt and were withdrawn from the study, and PA data for 12 children was lost due to accelerometer failure. In total, PA data was gathered for 78 children, over a median (range) of 7 days (1, 9) for 11.1 (2.4, 17.8) hours per day. Accelerometer counts were highly over-dispersed with a median dispersion parameter of 9.95 (4.17, 20.18). GEE modelling of the count data revealed a positive serial correlation between successive epochs (median 0.58, range 0.29, 0.76). Means of estimated daily average rates per second (on the natural logarithmic scale) ranged from 0.81 to 2.39 (median 1.72), meaning the median estimated average accelerometer counts per minute is $exp(1.72) \times 60 = 335.1$.

Average rate was not associated with any of the TV measures. Variation in estimated average activity rates was greater between children than within children (0.62 vs. 0.11). The Shapiro-Wilk's test of the regression's residuals revealed no evidence for non-normality, and no pattern or heterogeneity in plots of residuals by predicted values was found.

Table 14 shows the GEE results for body size measures and potential associates. Due to low paternal participation, paternal body size measures could not be considered. Maternal BMI was the only factor significantly associated with a greater risk of being overweight/obese (P=0.03). Compared with children of normal weight/underweight mothers, children of overweight/obese/otherwise mothers (classified by BMI status) were 2.43 times as likely to be overweight or obese (95% CI 1.11, 5.36). Child age had a significance value of P=0.07 in the univariable analyses, so was added with maternal BMI status to a multivariable GEE model for predicting the odds of a child being overweight or obese. Only maternal BMI status remained significantly associated with child body size in the multivariable model. Compared with children of normal weight/underweight mothers (classified by BMI status), the age-adjusted odds of a child being overweight/obese if their mother was overweight/obese/otherwise was 2.46 (95% CI 1.11, 5.48, P=0.03).

In the comparative univariable logistic regression analyses, child age and maternal BMI status were significantly associated with child WC status, and remained so when considered concurrently in multivariate logistic regression (child age OR 0.35, 95% CI 0.14, 0.85, P=0.02; maternal BMI OR 3.92, 95% CI 1.21, 12.69, P=0.02). While associations were in the expected direction for child BMI status, no significant relationships were found.

Table 14. Number of subjects (n), univariable and multivariable odds ratios (OR) and associated 95% confidence intervals (95% CI) of coefficient estimates from GEE analyses of relating various explanatory variables to children's body size (BMI and waist circumference)

	n	(%)	Univariable			Multivariable		
			OR	(95% CI)	P-value	OR	(95% CI)	P-value
Age	80		0.57	(0.31, 1.04)	0.07			
Average activity rate per day	78		0.38	(0.09, 1.73)	0.16			
Sex					0.38			
Male	38	(47)		Reference				
Female	42	(53)	0.92	(0.42, 2.03)				
Average daily TV/movie hours weekdays (hours/day)[a]					0.17			
0 – 0.9	13	(16)		Reference				
1 – 1.9	39	(49)	2.65	(0.76, 9.29)				
Otherwise	28	(35)	3.09	(0.83, 11.58)				
Average daily TV/movie hours weekend days (hours/day)[a]					0.57			
0 – 0.9	14	(18)		Reference				
1 – 1.9	28	(35)	0.99	(0.38, 2.55)				
Otherwise	38	(48)	0.92	(0.35, 2.41)				
Rooms in household with TV					0.25			
1	37	(46)		Reference				
≥2	43	(54)	1.54	(0.68, 3.48)				
Maternal BMI status[a]					0.03			0.03
Normal or underweight	46	(58)		Reference			Reference	
Otherwise	34	(43)	2.43	(1.11, 5.36)		2.46	(1.11, 5.48)	
Maternal trunk mass status[a]					0.15			
Normal or low	43	(54)		Reference				
Otherwise	37	(46)	1.72	(0.78, 3.79)				

[a] Note that some variables had missing observations as follows: TV/movie watching weekdays and weekend days (n=13), maternal BMI and trunk mass (n=7)

Discussion

This is the first study to investigate associations between body size, TV exposure, and objectively-assessed PA in preschool-aged children, accounting for both a child's WC and BMI, and using a novel approach to computing accelerometer data reduction. Factors related to risk of being overweight or obese were determined using a binomial GEE model to account for the within-child clustering of BMI and WC. Results showed that after accounting for child age, maternal overweight/obesity was associated with an increased risk of being overweight or obese in preschool-aged children, and no other significant associations were found. The null findings for TV exposure and body size were unexpected. Earlier studies have mostly demonstrated a positive relationship between TV watching and BMI and/or body fatness.[30-34,69,70,78] In their meta-analysis of PA, media exposure, and body fatness in preschoolers, Marshall et al.[248] found only small relationships between body fatness and TV hours (r=0.08; 95%CI 0.06, 0.08; P<0.01) or video/computer time (r=0.13; 95%CI 0.05, 0.19; P<0.01), indicating that although important, these variables are only one component of explaining weight status in preschool-aged children. It is likely that the small participant numbers produced insufficient statistical power for us to identify this relationship in the current study. Although non-significant, the contrasting odds ratios profiles for child body size and weekend and weekday TV watching indicate that such separation of TV exposure is worthy of further investigation. More detailed, objective, and sensitive information on TV watching patterns and other indicators of sedentary behaviours is also required.

TV and movie watching on weekend days was not associated with PA in our sample of preschoolers. Previous studies have shown contrasting results, with accelerometer-determined PA and hours of TV watching having either no association or a positive relationship with PA,[34,78] while a meta-analysis of PA (using various measurement methodologies) in children 3-18 years of age reported small negative relationships with TV time (r=-0.13; 95%CI 0.08, 0.11; P<0.01) and video/computer time (r=-0.14; 95%CI 0.08, 0.13; P<0.01).[248] Utilisation of differing measurement approaches impede better understanding this relationship, however, it is also likely that individual differences in TV and PA profiles further obscure any associations. Data from the Framingham

Children's Study indicate that such individual differences in activity profiles exist, whereby preschoolers exhibited various dimensions of PA and TV watching, and that health outcomes differed for each.[31] Body fat profiles were most favourable for children with high PA levels and low TV watching, followed by high PA, high TV, low PA and low TV, and low PA and high TV. Such categorisation of activity dimensions is likely to be worthwhile if we are to gain a comprehensive understanding of preschoolers' activity behaviours and their relationships with health outcomes and other factors, and identify individuals at risk.

Study Strengths and Limitations

The inclusion of WC as a component of body size is a novel and important addition to understanding activity dimensions and body size associations. Indeed, results from the comparative analyses (using traditional approaches of considering either BMI or WC) showed significant associations for child WC but not BMI (although relationships were in the expected direction). While analysing WC and BMI simultaneously adds complexity to the data treatment process, this method was considered as appropriate and important to understanding potential associates of children's body size.

In terms of clinical and epidemiological utility, the inclusion of BMI is essential to allow comparison with the substantial amount of international prevalence data and existing health research; the increasing levels of high WC in children disproportionate to BMI increases, combined with the stronger relationships between negative health outcomes and WC than for BMI in older populations make WC equally (or possibly more) important to measure. The concurrent treatment of these two variables thus allows for the consideration of these issues, while accounting for the collinearity between the factors and enabling a more comprehensive consideration of factors related to increased body size in young children.

Participants in the study were largely compliant, wearing the accelerometer belts for a median of 6.2 days thereby providing detailed PA profiles and considerable accelerometer data. The innovative approach taken to accelerometer data reduction in this study eliminated issues with data treatment including calculating intensity thresholds and defining a 'day', and allowed for all data to be included in analyses. Stringent tests were employed to ensure the analytical approaches and data distribution assumptions made were appropriate. The small sample size in the present study was the main study limitation, and considerably limited the power to detect any significant differences. A larger number of study participants would have proffered better opportunities to identify and elucidate these relationships between PA, TV exposure, and body size in young children. Encouraging families of preschool-aged children to participate in studies of this nature may pose considerable challenges for PA researchers.

Conclusion

Contributors to the high and increasing prevalence of overweight and obesity in preschool aged children are complex and likely to exist in multiple facets of young children's lives. Application of an ecological approach to identifying risk factors and providing intervention for increased body size in preschoolers is needed.

Chapter 8: Discussion and Conclusion

PA in Preschoolers: The Wider Context

The current health climate in developed and developing countries is one of increasing lifestyle related diseases that can be directly attributable to insufficient PA participation and/or increased inactivity. Research indicates that young children in developed countries are exhibiting high and increasing levels of overweight and obesity,[38] and many exceed recommended levels of sedentary behaviours.[243] Accordingly, individual and macro-environmental changes are essential to encourage population-wide changes in PA and sedentary behaviours. Government-level support for this exists in NZ with policies such as the NZ Health Strategy,[249] the HEHA strategy,[59] SPARC's Active Movement programme,[250] and the recent inclusion of non-communicable disease prevention in the 2007 Public Health Bill.[251] As they currently exist, however, these strategies are missing key opportunities to improve PA and reduce obesity and sedentary behaviours in preschool-aged children. They predominantly focus on nutrition-related aspects of weight control, and strategy components that do consider PA or sedentary behaviours are descriptive, rather than prescriptive, so are largely open to interpretation. Education and self-regulation are also promoted as key strategies to improve PA and reduce sedentary behaviours; however, past attempts to improve health behaviours using such approaches have shown that that these strategies alone are likely to be ineffective. Historical approaches to smoking cessation provide the most evidence for this, whereby legislation-induced changes to social and physical environments that people were exposed to caused instant and substantial reductions in smoking prevalence, compared with previous minor changes due to education-based strategies.

Strong regulatory guidance is needed for the creation of environments that are conducive to PA and discourage unhealthy levels of sedentary behaviours in young children. Possible examples include the implementation of a PA curriculum in ECE settings, and ensuring the NZ Education (ECE) Regulations[24] provide for adequate indoor and outdoor play space. Reconsideration of Section 16 (noise pollution) of the Resource Management Act 1991 (RMA)[252] would also

be beneficial; the current legislation considerably restricts opportunities for outdoor play in urban ECE settings due to noise pollution created by children's play. Prioritisation of PA within the RMA could also improve opportunities for active transportation and access to safe playgrounds at the community level, and provide increased PA opportunities in future community and individual-level developments. Irrespective of the actual approaches taken, the current lack of direct legislative direction means that communities, educators, and families are left to shape the environments in which young children exist, with indeterminate outcomes.

The present research sits within multiple contextual levels of PA in preschool-aged children. The essence of this thesis was to draw from, and add knowledge to, the limited body of work in PA and health in early childhood. Overarching aims of the thesis were to investigate and critique measurement methodologies for PA quantification in preschool-aged children (to inform research at the individual, family, ECE, and wider community levels), and to apply these findings in research to identify individual- and family-level associates of PA in preschoolers.

Research Summary and Implications

This body of work makes a number of contributions to the field of PA in preschoolers. Literature review findings showed that PA in preschoolers was beneficial to bone health and weight status, while sedentary behaviour was negatively related to physical health. There was insufficient evidence to determine associations between PA and cognitive development, insulin resistance, or cardiovascular disease risk factors for preschool-aged children. Environmental contexts (particularly family- and ECE-level) of preschoolers were found to be important considerations as potential influencers of preschool PA. Dose-response relationships for amount and types of PA and health in preschoolers were nonexistent, and there was a paucity of robust information on PA and sedentary characteristics of young children. Although motion sensor use was deemed most appropriate for accurate quantification of PA patterns over multiple days, pedometer accuracy was yet to be established, and numerous issues related to accelerometer data reduction remained unresolved.

These review findings set the context and formed the thesis direction by establishing the need to further investigate objective approaches (pedometry and accelerometry) to measuring PA in preschool-aged children, and identifying the importance of determining preschool PA associates to target for intervention. In Chapter 4, pedometer accuracy was variable when compared with direct observation methodology and observed steps. Accuracy was lowest when pedometers were placed at the back of the child (compared with hip placement), and/or when the child was walking slowly (as opposed to running or walking normally). As such, these monitors were considered unsuitable for research purposes in this body of work. If research goals are to determine activity prevalence or determine PA intervention effectiveness in preschoolers, the use of existing pedometers is not recommended. Nonetheless, given their affordability and ease of translating measurement units to individuals, pedometers may still be useful as motivational tools (rather than outcome measures) in PA interventions with preschoolers and their families. If this was the case, the application of a secondary measure (e.g., accelerometry, direct observation) would be needed to support any PA measurement findings.

In Chapter 5, accelerometer utility was investigated, whereby the efficacy of accelerometer count thresholds to describe PA intensity in preschoolers was assessed. Compared with second-by-second direct observation data, existing accelerometer thresholds systematically misclassified and underestimated PA intensity in the study participants. The existing application of accelerometer thresholds with young children was deemed fundamentally inappropriate, with postulated reasons being that threshold calibration is based on behaviours uncharacteristic of preschoolers and epoch durations are insufficiently short to capture intermittent behaviours that may be idiosyncratic of young children. It was also purported that considerable diversity in individual physical development may affect accelerometer output, and that uniformly determined and employed accelerometer count thresholds would fail to account for these developmental differences. These findings have substantial implications for the interpretation of existing preschool PA research and future study designs.

Future studies should consider alternative approaches to using count thresholds for describing PA in preschoolers. This may involve similar data reduction processes as those outlined in this thesis, or the combination and comparison of multiple approaches and tools to determine the most appropriate method. Existing research has predominantly used accelerometer count thresholds to describe PA levels and associates in preschoolers (Table 2). Our findings indicate that this previous research is likely to have misclassified and underestimated actual activity levels, resulting in ubiquitous inaccuracies in activity description and identification of PA associates in young children. Replication of these studies using alternative approaches to accelerometer data reduction is needed to confirm the accuracy of relationships previously identified for preschoolers' PA.

While the above findings challenged existing commonly used protocols, they also provided explanatory evidence for the numerous contentious issues reported by child PA researchers attempting to quantify PA level with accelerometer count thresholds.[169,171,236] This was also the first study to collect such detailed information on the PA behaviours of preschool-aged children, so simultaneously provided basic yet important descriptive information of activity types and durations in preschool-aged children.

The ensuing study involved developing a robust procedure for analysing accelerometer data collected with preschool-aged children and their parents, and used this procedure to investigate familial associates of preschoolers' PA (Chapter 6). Because of the many problems associated with interpreting accelerometer data described earlier (Chapters 3 and 5), the use of raw accelerometer data is recommended, however, accelerometer data is difficult to analyse and interpret in raw form. Accordingly, the current research sought to reduce the raw accelerometer data in an appropriate manner by estimating average daily activity rates from the raw accelerometer data using GEE methodology. This method produced an easily understandable measure of PA behaviour and eliminated the use of count thresholds for classifying PA. Based on an underlying assumption that individuals with partial days yielded rates that were not systematically different from full-day data, all data could be included in the analyses, irrespective of the amount of data collected.

This method is of particular relevance to researchers using accelerometry in population studies, given the frequency with which data may be lost or missing due to inadequate participant compliance, lost accelerometers, or unit failure. Preliminary exploration of the raw count data showed variance in activity patterns over differing days, irrespective of the length of time measured for a day (Figure 5). More detailed analysis showed moderate correlations between successive epochs for individuals, and within-individual variation was sufficiently lower than between-individual variation to detect differences between participants. Data were successfully reduced to estimated daily values for individuals, and distributional and residual checks confirmed assumptions made and methods applied were appropriate. It must be noted that it is still very difficult to ascertain the 'quality' of raw accelerometer data when undertaking such analyses, and more critique in this area is required. Repeated-measures analyses were conducted using GEE methods to determine familial associates of preschool-aged children's PA. A small positive association between child PA and that of their parents (average of maternal and paternal PA) was found, providing evidence for the contributory role of the family environment in encouraging PA in preschoolers.

Although a useful approach to explain PA, the quantification of average activity rates precluded the measurement of sedentary behaviour. As found in Chapter 2, sedentary behaviour is important to consider as well as, and separately to, PA when investigating body size and health in young children. In addition, although WC has been related to health outcomes in young children, this factor has been relatively under-reported in studies of PA, sedentary behaviours, and body size. The final research chapter (Chapter 7) thus involved exploring the effect of PA and indicators of inactivity (TV watching time, household TV ownership, TV in bedroom) on the body size of young children.

This was the first study to consider associations between body size, TV exposure, and accelerometer-determined PA in preschool-aged children, using children's WC and BMI, and a novel approach to computing accelerometer data reduction. Variables potentially related to being overweight or obese were investigated using binomial GEE modelling.

Results showed that after adjusting for child age, maternal overweight/obesity was associated with an increased risk of being overweight or obese in preschoolers. No significant associations for child body size were found with PA or TV exposure, likely due to small participant numbers decreasing statistical power to detect any relationships, the relatively imprecise measure of TV time (compared with comprehensive PA data), and homogeneity of the TV categorisations used. Further, while BMI and/or body fatness have been previously associated with TV watching time or PA, these associations have often been small, indicating that although contributing factors, investigation of further variables is needed to explain body size in preschoolers. Importantly, practical recommendations for future research were determined from this research, including: separating TV exposure by weekdays and weekend days, gathering more detailed information on TV watching patterns (e.g., more sensitive categories of TV watching time) and other sedentary behaviours, and categorising individual PA/inactivity dimensions when investigating factors related to preschoolers' body size.

A number of contributions to the field of preschool PA research were made from this body of work. Detailed analysis of the current state of knowledge in preschool PA assessment and associates of PA in preschoolers was provided. Results from two empirical studies provided evidence for the utility of accelerometers with preschool-aged children, but not for pedometers or the application of accelerometer count thresholds to describe PA intensity. Of note, a novel approach to objective quantification of PA was developed and explained using robust contemporary statistics. Individual- and family-level factors related to preschoolers' PA and body size were investigated using contemporary statistical procedures, with child age and parental PA identified as significant independent associates of PA, and maternal BMI as a risk factor for increased child body size.

Study Limitations

Limitations of the present research were:

1. Statistical analyses were hampered by small sample sizes, in particular low parental (especially paternal) involvement in Chapters 6 and 7. Consequently, it is likely there was insufficient statistical power to detect effects. Nonetheless, this research provides the rationale and findings to inform a larger, fully powered study to be conducted, so still holds much utility.

2. Convenience sampling was used to recruit study participants from regions of Auckland, NZ for the studies in Chapters 6 and 7. A low response rate (14%) meant that there was undoubtedly selection bias, and respondents were predominantly NZ European. As such, the data gathered were not necessarily representative of the variability in behaviours and characteristics seen in young children.

3. It is possible that the children moved the accelerometer and pedometer belts horizontally around their waist, causing inconsistency in results. This was not applicable for the empirical studies in Chapters 4 and 5, as the researcher observing the child would have halted the measurement procedure upon observing the child tampering with the motion sensors or belts. The significant amount of data gathered over multiple days for children in Chapters 6 and 7 meant that such belt movement (if any) would be unlikely to influence the overall PA rates calculated. While monitors could be secured to the child's clothing instead of a belt, this approach is not possible when children are wearing dresses or overalls. The use of elastic belts is ideal, as they are non-intrusive, and provide a level of consistency of monitor placement, irrespective of type of clothing worn.

4. Parental-proxy report was used to gather information on TV watching hours of their preschool-aged child in Chapter 7, potentially resulting in bias. Considering that the majority of children did not have a TV in their bedroom, it is likely that if there was any bias, parents would have actually over-reported the TV watching of their child.[207] More accurate data may be gathered with objective methods such as TV allowance monitors, however, this was not feasible in the current research.

5. Accelerometer reliability was not assessed prior to implementation of the monitors in Chapters 5-7. Although the manufacturers report high between-unit reliability and minimal variance between units, it is possible that variance in output between units existed. Because consistency in results was found between individuals and monitors in the studies, and the focus of the research in Chapters 6-7 was on data patterns rather than absolute counts, the implications of this on the current research findings are likely to be minor or nonexistent. Even so, reliability assessment and calibration of monitors in any future research of this type is considered worthwhile to strengthen the study design and confidence in research findings.

Future Research

A multilevel approach that considers potential associates of PA in preschoolers within the individual child and the wider contexts that may influence children's activity is needed. Understanding relationships between preschool PA and potential factors at multiple levels (individual, family, neighbourhood, community, policy, etc.) is likely to be most effective to inform PA intervention and facilitate behaviour change. For preschoolers, examples of multilevel factors that may be related to preschool PA are child demographics, family structure, parental and sibling PA, ECE attendance and environment, access to neighbourhood parks and outdoor play spaces, measures of neighbourhood safety, existence of community programmes for preschool PA, and legislative supports for PA in ECE. The current research developed and reported a multilevel approach to the estimation of PA, whereby individual- and family-level associates of PA and body size were assessed. Further work including the community, built environment, societal, and legislative contexts of young children is required to understand preschool PA associates and for the implementation of comprehensive PA interventions. Ideally, this would be achieved internationally through birth cohort studies that included measurement of PA in children and their families, potential PA associates at multiple levels, and health outcomes of PA throughout the lifespan. Where practicable, the addition of PA measurement in children and their families to existing cohort studies would also provide important information on associations between early life factors and PA behaviours in children.

At the family level, parental PA was related to the activity of their preschool-aged child, and maternal body size was related to that of their child. Accordingly, preschool PA interventions should include the promotion of PA for children and their parents/caregivers. Parents may be more amenable to changing their own behaviours if they understand this influences the health and wellbeing of their child. Involving parents in this manner would therefore have a twofold benefit – increased PA and health status in both children and also their parents. Encouraging PA in the preschool child also increases the likelihood of continued PA and reduced health risk in later life. While family-level research was shown to be important when investigating preschool PA associates in the present study, encouraging families to participate in the research was challenging. Future studies would benefit from developing strategies to encourage participation of children and all available parents/caregivers.

Inactivity and PA are activity dimensions that are important to measure both separately and collaboratively in young children when investigating factors related to body size. Consistent with previous research, the majority of the young children in the current study watched TV, indicating this is a relevant indicator of sedentary behaviours in this population. More sensitive categorisation of TV watching time (e.g., in 15- or 30-minute categories) is needed to elucidate the relationships between TV exposure and body size and PA in young children. The collection of information on additional indicators of sedentary behaviours in this population would also be beneficial. Consideration of TV exposure on weekdays and weekend days separately, and the use of an objective measure of sedentary behaviours (e.g., TV allowance monitors, ActivPAL monitors) in future studies is recommended. ActivPAL monitors hold particular utility for the objective quantification of inactivity in children by measuring time spent sitting, standing, and walking. As well, this approach to describing activity (sit, stand, walk) may provide more meaningful and appropriate information than pedometer steps or accelerometer counts to explain activity behaviours in young children.

Accelerometers are the most widely used tools for objective assessment of PA in preschoolers; however, these monitors are not without limitations. Increased PA intensity from load carriage and gradient changes cannot be assessed, and if worn at the hip, PA from upper body movements and activities such as cycling is not accurately measured. Although accelerometers allow for the collection of objective PA data, the actual quality of data gathered has not been investigated. Detailed analysis and critique of the distributions and frequencies of accelerometer counts gathered over differing time periods is needed in future calibration studies.

While accelerometers enable the collection of vast amounts of data, this in itself can be challenging for researchers in terms of reducing the data in an appropriate manner. Statistical methods are quickly evolving, enabling researchers to handle large datasets. Paradoxically, this evolution is problematic, with increased statistical complexity and analysis options leaving researchers struggling to identify a 'best practice' approach to preschool accelerometer data reduction. One possible approach to accelerometer data treatment is introduced in this thesis; replication and critique with larger sample sizes would be useful to confirm the utility of this approach.

Advancing accelerometer technologies have also allowed for progressively greater data storage capacities, shorter epoch lengths, collection of multiple PA measures (e.g., accelerometer counts and step counts in the newest Actical monitors), smaller (and thus less obtrusive) monitors, units that can be worn at differing body positions, and purported improvements in functioning and reliability. Consequently, preschool PA researchers are faced with numerous methodological decisions to make when using accelerometers, with no best practice recommendations available.

While accelerometers are arguably the best method to objectively quantify PA in preschoolers to date, considerably more work is required to assess the accuracy and practical application of these monitors with young children, and to develop methodological recommendations specific to preschool-aged children.

When Actical accelerometer technologies evolve such that epoch lengths shorter than 15 seconds (i.e., approaching 1 second) can be employed, reinvestigation of the utility of count thresholds using these accelerometers would also be useful. If this was the case, threshold calibration must involve activity types and durations characteristic of young children's behaviours, and the development of specific thresholds for preschoolers of differing ages and developmental stages would also be worthwhile.

Conclusion

Early childhood is unquestionably an important life stage to target for developing PA patterns and preventing lifestyle related disease. This research has provided an alternative robust method for quantifying PA in preschool-aged children, and has identified factors important for interventions to encourage improved PA and health status in this population. Development of efficacious PA interventions is urgently required. Further investigation of factors related to PA in preschoolers at multiple contextual levels is needed to inform effective PA intervention development and implementation.

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Appendices

Appendix A: AUTEC approval for study investigating pedometer and accelerometer utility

AUT
AUCKLAND UNIVERSITY OF TECHNOLOGY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

MEMORANDUM

Academic Services

To: Grant Schofield
From: **Madeline Banda**
Date: 6 April 2005
Subject: Ethics Application Number 05/41 **Pedometers and accelerometers: reliability and convergent validity in children aged 3-5 years.**

Dear Grant

Thank you for providing written evidence as requested. I am pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC) at their meeting on 14 March 2005. Your ethics application is now approved for a period of three years until 6 April 2005.

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 at *http://www.aut.ac.nz/research_showcase/pdf/appendix_g.doc*, 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 at *http://www.aut.ac.nz/research_showcase/pdf/appendix_h.doc*. This report is to be submitted either when the approval expires on 6 April 2005 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 917 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: Melody Oliver melody.oliver@aut.ac.nz

From the desk of ...   Private Bag 92006, Auckland 1020   Tel: 64 9 917 9999
Madeline Banda   New Zealand   ext 8044
Academic Services   E-mail: madeline.banda@aut.ac.nz   Fax: 64 9 917 9812
Student Services

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Appendix B: AUTEC approval for amendments to study investigating pedometer and accelerometer utility (added straight line walking to study protocol)

AUT
AUCKLAND UNIVERSITY OF TECHNOLOGY
TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

MEMORANDUM

Academic Services

To: Grant Schofield
From: **Madeline Banda**
Date: 20 July 2005
Subject: Ethics Application Number 05/41 **Pedometers and accelerometers: reliability and convergent validity in children aged 3-5 years.**

Dear Grant

I am pleased to advise that a minor amendment allowing an additional data collection was approved by the Chair under delegated authority subject to endorsement at the meeting on 8 August 2005.

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 6 April 2005 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: Melody Oliver melody.oliver@aut.ac.nz

From the desk of ...   Private Bag 92006, Auckland 1020   Tel: 64 9 921 9999
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Student Services

Appendix C: AUTEC approval for second amendments to study investigating pedometer and accelerometer utility (added video footage of outdoor free play to study protocol)

AUT
UNIVERSITY
TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

MEMORANDUM
Auckland University of Technology Ethics Committee (AUTEC)

To: Grant Schofield
From: **Madeline Banda** Executive Secretary, AUTEC
Date: 2 March 2007
Subject: Ethics Application Number 05/41 **Pedometers and accelerometers: reliability and convergent validity in children aged 3-5 years.**

Dear Grant

I am pleased to advise that the Chair of AUTEC has approved amendments to your ethics application permitting the use of video recording to verify the measurements. This delegated approval is made in accordance with section 5.3.2 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement at AUTEC's meeting on 12 March 2007.

I advise that as part of the ethics approval process, you are required to submit to AUTEC the following:

- A brief annual progress report indicating compliance with the ethical approval given using form EA2, which is available online through *http://www.aut.ac.nz/research/ethics*, including when necessary a request for extension of the approval one month prior to its expiry on 6 April 2008;

- 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 6 April 2008 or on completion of the project, whichever comes sooner;

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

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

Please note that AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to make the arrangements necessary to obtain this.

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: Melody Oliver melody.oliver@aut.ac.nz

From the desk of …   Private Bag 92006, Auckland 1020   Tel: 64 9 921 9999
Madeline Banda   New Zealand   ext 8044
Executive Secretary   E-mail: madeline.banda@aut.ac.nz   Fax: 64 9 921 9812
AUTEC   page 1 of 1

Appendix D: AUTEC approval for child PA and TV time, obesity, and parent PA measurement study

AUT
UNIVERSITY
TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

MEMORANDUM

To: Grant Schofield
From: **Charles Grinter** Ethics Coordinator
Date: 21 August 2006
Subject: Ethics Application Number 06/116 **Physical activity in preschoolers and their parents: amount, associations, and accounts.**

Dear Grant

Thank you for providing written evidence as requested. I am pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC) at their meeting on 21 June 2006 and that AUTEC has approved your ethics application at their meeting on 14 August 2006.

Your ethics application is approved for a period of three years until 14 September 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 14 September 2009 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 me 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

Charles Grinter
Ethics Coordinator

On behalf of Madeline Banda, **Executive Secretary, AUTEC**

Cc: Melody Oliver melody.oliver@aut.ac.nz

From the desk of ...   Room WA208, Level 2, WA Building, Wellesley Campus D-81   Tel: 64 9 921 9999
Charles Grinter   Private Bag 92006, Auckland 1142   ext 8860
Ethics Coordinator   New Zealand   Fax: 64 9 921 9812
Academic Services   E-mail: charles.grinter@aut.ac.nz   page1 of 1

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Appendix E: Participant feedback

Results Sheet: Physical activity in Auckland preschoolers and their parents

Dear PARTICIPANT NAMES HERE,

Thank you for your involvement in this study. Graphs of activity measured by the accelerometers are provided below. Your individual results and further information is also provided in the following pages. If you have any questions about these results, or the study in general, please feel free to contact the project supervisor or researcher at any time, at the contact details provided at the end of this sheet.
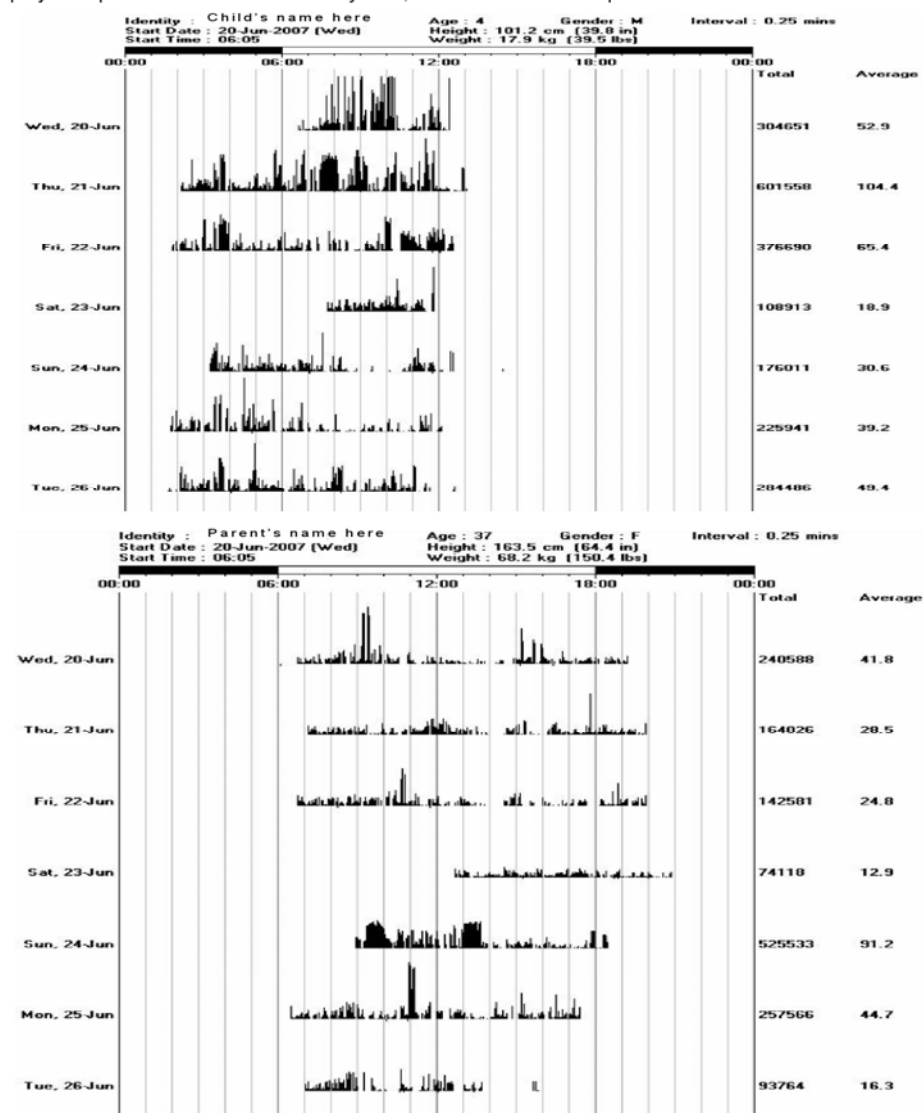
Physical activity

Graph 1: This graph shows the minutes of light activity (e.g., playing in a sandpit, walking), and moderate-vigorous activity (e.g., walking quickly, skipping, running) that your child did while they wore the accelerometer. The remainder of time was spent in sedentary activities (e.g., naps, watching TV, etc).
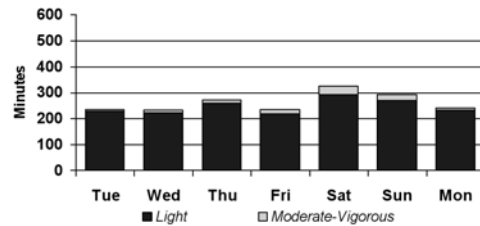
At present, it is not known exactly how much physical activity pre-school aged children should be doing for their health. What we do know is that children who are more active have better bone health and motor skill development, and are less likely to be overweight or to have risk factors for cardiovascular disease than children who are less active. The above graph shows you whether your child was more or less active on particular days, such as weekends versus weekdays. It might help to think back to these days and remember what your child did that helped them to be more or less active, so that you can plan for activity whenever possible. Another way to think about activity is to look at what percentage of time is spent in sedentary activities. Approximately 75% of preschoolers' time is spent being sedentary, and only 5% of time is spent in vigorous activities. Increased sedentary time (e.g., watching over 2 hours of television daily) is associated with an increased risk of being overweight in young children, and some US researchers have suggested that ideally, children should not be sedentary for more than 60 minutes at a time (except when sleeping).

Graph 2: This graph shows the percentage of time your child spent in sedentary, light, and moderate-vigorous activity on each day the accelerometer was worn. Ideas for increasing physical activity and reducing sedentary activity are provided at the end of this report.
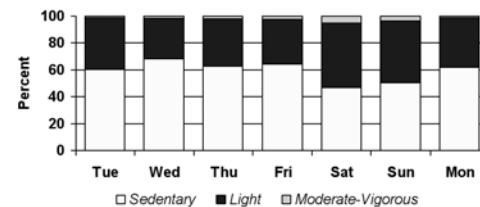
Body mass index (BMI): 16.5 kg/m^2

BMI is calculated using height and weight, and is a rough estimate of weight status. Overweight children are more likely to develop risk factors for cardiovascular disease and diabetes, and are at much greater risk of developing adult obesity. Ideally boys aged 3-5 years should have a BMI of less than 18 kg/m^2, and girls less than 17.5 kg/m^2. If your child has a higher BMI than this, they may benefit from improved physical activity and nutrition.

Waist circumference: 50.0 cm

Having a high waist circumference is related to an increased possibility of having risk factors for cardiovascular disease in early childhood. For girls, a waist circumference of less than 50.3cm at 3 years of age, 53.3cm at 4 years, and 56.3cm at 5 years is ideal. In boys, a waist circumference of less than 53.1cm at 3 years of age, 55.6 at 4 years, and 58cm at 5 years is ideal. If your child's waist circumference is higher than these values, they may benefit from improved physical activity and nutritional practices.

Physical activity

Graph 1: This graph shows the minutes of light activity (e.g., hanging out washing), moderate activity (e.g., brisk walking), and vigorous activity (e.g., running) that you did while you were wearing the accelerometer. The remainder of time was spent in sedentary activities (e.g., watching TV).
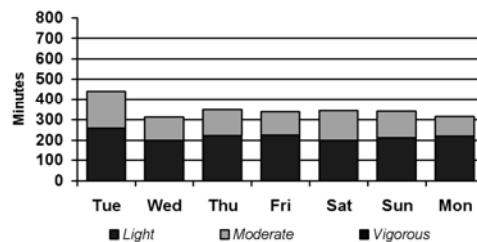
Regular, moderate intensity physical activity in adults is associated with a reduced risk of mortality, cardiovascular disease, diabetes, obesity, depression, osteoporosis, and some cancers. To achieve these benefits, it is recommended that adults accumulate at least 30 minutes of moderate activity (such as brisk walking) on 5 or more days per week. Increased benefit can be gained from being even more active than this. It might help to think back to the days you wore the accelerometer and remember what you did to make you more or less active, to help you identify activities that contributed to your overall physical activity level.

Graph 2: This graph shows the percentage of time you spent in sedentary, light, moderate, and vigorous activity on each day the accelerometer was worn. It is often interesting to compare the types of activity that you are doing with those of your child, to see whether there are any similarities in your activity patterns.
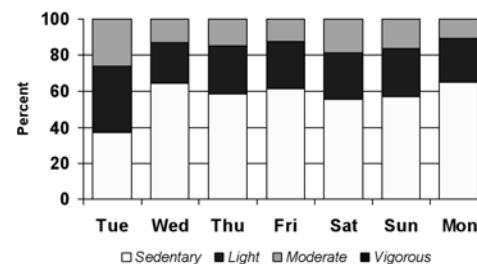
You may notice that your results are presented slightly differently to your child's. This is because young children move differently to adults as they are developing, and so the accelerometer information has been analysed differently for children and adults. It is also important to note that because the accelerometers are worn at the hip, they do not measure some activities well, for example, cycling, and weight training exercises where there is limited trunk movement. If you do a lot of these types of exercise, your results will underestimate the amount of activity that you do.

Body mass index   25.3 kg/m^2

If your BMI is more than 25 kg/m^2, and you are not regularly physically active, then you are more likely to be at risk of a number of lifestyle related diseases such as cardiovascular disease and diabetes. BMI can be reduced by increasing physical activity, and improving nutritional habits. Further information is provided at the end of the report.

Waist circumference   76.5 cm

There is little information available on healthy ranges of waist circumference measurements for differing ethnic groups. In adult Europeans, a waist circumference that is more than 80 cm for women and 94 cm for men, combined with an inactive lifestyle, is associated with an increased risk of developing diabetes. As with BMI, waist circumference can be reduced with physical activity and healthy eating.

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Some of the questions you may have are answered below:

How can we improve our physical activity levels?

- Be a positive role model for your child – they learn by imitation, and you are their #1 hero
- Different activities work for different people – try new activities and see what you like
- Spend time outside – children are generally more active outdoors than indoors
- Start at your own pace and build up gradually. If you or your children have not been very active before, you might like to try getting outside and walking for just 5 minutes together every day
- If you cannot spare 30 minutes to be active, break your activity up into 10-minute bouts
- Park your car (or get dropped off) further away from the shops and walk together
- Whenever possible, walk instead of driving
- Take the dog for a family walk in your local park
- Swap TV time for family time. If children are watching TV, try to choose programmes that encourage activity, dancing, etc. (e.g., Hi-5)
- It may take around 6 weeks before you begin to feel the benefits of being active, so remember to keep it up!

What about food?

Appropriate nutrition can also be beneficial for weight status and improved wellbeing.

Key points to remember are:

- Positive role modelling is important at meal times also – try to have meals together when possible and think about what you are teaching your children with your own eating behaviours
- Limit saturated fat, sugar, and salt intake
- Try to eat plenty of wholegrains, beans, and lentils
- Eat 5+ portions of fruit and vegetables of different colours daily
- Eat breakfast daily and plan for healthy snacks between meals
- Avoid eating large portion sizes at meal times
- Limit soft drink intake and drink plenty of water. If your child does not currently drink water, get them used to it by adding some fruit juice to the water, and slowly decrease the amount of juice you add each time
- Food items with the National Heart Foundation tick are easy healthy options when food shopping
- A recent article in the Healthy Food Guide Magazine suggested that children sometimes need to try something up to 15 times before they will accept it, so don't be afraid to try new foods together and persist with them!

Where can I get more help?

Your Regional Sports Trust

Call 0800 ACTIVE (228483) to get in touch with your local sports trust. Active Movement Coordinators there can help you with activity ideas for young children, and they can also help you find activities in your area that you may like. Information can also be found at www.sparc.org.nz.

Your family General Practitioner

You may wish to discuss these results with your family GP. They can provide guidance and information to help your family with your physical activity and/or nutrition goals. Your GP may also prescribe a Green Prescription, a program run by Regional Sports Trusts to help people incorporate physical activity into their everyday lives.

Researcher Contact Information

Project Supervisor: Grant Schofield, grant.schofield@aut.ac.nz, ph 9219999, x7307
Researcher: Melody Oliver, melody.oliver@aut.ac.nz, ph 9219999, x7848

Appendix F: Participant questionnaire

Physical activity in preschoolers: Questionnaire 1   CODE: ____

Researcher use only (read questions 3 onwards aloud and circle or write answer where appropriate):

Child's Name: _____   Mother's Name: _____

Father's Name: _____   Date: _____

Email: _____   Phone: _____

Address: _____

Recruited from: _____

1. Child sex   Male[1]/Female[2]

2. Type of dwelling   Standalone unit or townhouse[1]/Attached unit or townhouse[2]/Moveable dwelling[3]

"Thank you for taking the time to answer the following questions. This brief questionnaire will help us understand more about your child's activity patterns and factors that might be associated with activity. All answers will be kept completely confidential. You can choose to not answer any questions that you are not comfortable with."

3. What is your child's birth date?   _____dd/_____mm/_____yy

4. What was your child's birth weight?   _____kg   OR   _____lb, _____oz

5. Was your child born prematurely *(born <37 weeks gestation*)*?*gestation is 2 weeks longer than fertilization age* Yes[1]/No[2]

6. If your child was born prematurely, by how many weeks was he/she premature?   _____ weeks

7. What ethnic group do you most identify your child with *(ideally only choose 1)*?

    NZ Euro[1]/Maori[2]/Samoan[3]/Cook Island Maori[4]/Tongan[5]/Niuean[6]/Chinese[7]/Indian[8]/Other[9](state) _____

8. If your child has any other young people (of school age) living with them, could you please tell me their age and relationship to your child (e.g., brother, 7 years, 2 months):   _____ , _____ y, m

    _____ , _____ y, m

    _____ , _____ y, m

    _____ , _____ y, m

9. How many parents or caregivers regularly live with your child *(this means sleeping in the same household for four or more nights per week)*?   One[1]   Two[2]   Three+[3]

10. How many rooms in your household have a television?   One[1]   Two[2]   Three[3]   Four+[4]   None[5]

11. Does your child have a television in his or her room?   Yes[1]/No[2]

12. Does your household have SKY?   Yes[1]/No[2]

13. Is your child allowed to watch dvds/videos in your household?   Yes[1]/No[2]

14. Is your child allowed to use a games console (e.g., Playstation, Xbox) in your household?   Yes[1]/No[2]

15. Is your child allowed to use a personal computer in your household (for play or learning)?   Yes[1]/No[2]

16. How many motor vehicles (excl. motorbikes) do you have available for your family's unlimited use?   One[1]/Two[2]/Three+[3]/None[4]

17. On a scale of 1-5, if 1 is very inactive and 5 is very active, how active do you consider your child to be?   1(very inactive)[1] / 2[2] / 3[3] / 4[4] / 5(very active)[5]

18. On a scale of 1-5, if 1 is very inactive and 5 is very active, how active do you consider yourself to be?   1(very inactive)[1] / 2[2] / 3[3] / 4[4] / 5(very active)[5]

Physical activity in preschoolers: Questionnaire 2   CODE: _____

Child's Name: _____   Date: _____

"Thank you for participating in the study over the previous week. This questionnaire will help us understand more about your child's activity in the previous week, and factors that might be associated with their activity. All answers will be kept completely confidential. You can choose to not answer any questions that you are not comfortable with."

In the week following our first home visit,

45. approximately how many hours did your child watch TV/movies on each weekday? _____ hrs/day

46. approximately how many hours did your child watch TV/movies on each weekend day? _____ hrs/day

In the week following our first home visit, on how many days…

	None[1]	1-2[2]	3-4[3]	5-6[4]	7[5]	N/A[6]
19. were rules applied about TV/movie watching on the weekdays?	☐	☐	☐	☐(5)		☐
20. were rules applied about TV/movie watching on weekend days?	☐	☐(1)	☐(2)			☐
21. were rules applied about game console use (if applicable)?	☐	☐	☐	☐	☐	☐
22. were rules applied about computer use (if applicable)?	☐	☐	☐	☐	☐	☐
23. did your child have restrictions on, or rules applied about outdoor play?	☐	☐	☐	☐	☐	☐
24. were you physically active with your child?	☐	☐	☐	☐	☐	
25. did you encourage your child to be physically active?	☐	☐	☐	☐	☐	
26. did your child play outdoors (home and park)?	☐	☐	☐	☐	☐	
27. did you take your child to a park, playground, beach, etc.?	☐	☐	☐	☐	☐	
28. did your child eat breakfast?	☐	☐	☐	☐	☐	
29. did your child eat takeaways or fast food (*any food purchased and not prepared at home)?	☐	☐	☐	☐	☐	
30. did your child have a sugary drink *(including fruit juice)*?	☐	☐	☐	☐	☐	
31. eat 5 or more servings of fruit and vegetables *(1 serve is a child's fist size)*?	☐	☐	☐	☐	☐	
32. did your child have a DAYTIME nap?	☐	☐	☐	☐	☐	☐

    45. for approximately how many hours? _____ hrs

33. did your child attend any form of early childhood education/care?	☐	☐	☐	☐	☐	☐

    34. for approximately how many hours each day? _____ hrs

    35. and what type of setting is it (kindergarten, playgroup, etc.) _____

36. did the main caregiver work?	☐	☐	☐	☐	☐	☐

    37. for approximately how many hours each day? _____ hrs

In the week following our first home visit, what time did your child normally…

38. Go to bed on a weekday? _____ pm

39. Get up on a weekday? _____ am

40. Go to bed on Saturday? _____ pm

41. Get up on Sunday? _____ am

42. Were there any days that the accelerometer was not worn by your child? (if so, days/times?) _____

43. Were there any days that the accelerometer was not worn by you? (if so, which days/times?) _____

44. Were there any days that the accelerometer was not worn by the second parent/caregiver? (if so, which days/times?) _____

"That now concludes your involvement in the study. Thank you again for your time and participation."

Appendix G: Physical activity in early childhood: Current state of knowledge

Original Research Review

Physical Activity in Early Childhood: Current State of Knowledge

Melody Oliver and Grant M. Schofield
Auckland University of Technology

Gregory S. Kolt
University of Western Sydney

Claire McLachlan
Massey University

Abstract

This paper provides findings from a review of literature relating to physical activity (PA) in the early childhood years (children aged <5 years). Activity in early childhood may confer considerable health gain, including improved bone health and a reduced risk of being overweight. Increased sedentary time may have a negative influence on physical health. Exactly how much PA is required, and what types of activity are important for health gain in young children is yet to be determined. There is a paucity of information pertaining to PA and cognitive development, insulin resistance, and cardiovascular disease risk factors for this age group. As well, there is limited information regarding the activity profiles of pre-school children, and the determinants of both PA and sedentary behaviour. It is likely that factors in both the family and early childhood centre environments are related to PA and/or sedentary behaviours. Knowledge regarding PA and early childhood health, development, and learning is limited. Longitudinal research is required to track PA patterns of young children, identify potential health outcomes, and social and environmental determinants of PA and sedentary behaviour in early childhood and beyond. Collaborative links between health and education providers and PA and health researchers are required to promote consistent PA messages.

Key Words: Physical activity; sedentary; early childhood; health

Introduction

PA is defined as any bodily movement requiring energy expenditure. Within an early childhood education centre context, this refers to both fine (e.g., painting) and gross (e.g., running, skipping) body movements. PA in early childhood (children aged <5 years) has traditionally been assessed using proxy questionnaires (Saakslahti et al., 1999) or direct observation (Sallis et al., 1993), both of which are subjective measures that can lead to bias and inaccuracy (Sirard & Pate, 2001). More recently, motion sensors such as accelerometers have been used to gather more objective, accurate, and detailed information on the amount and level of activity in young children (Reilly et al., 2004).

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The importance of PA and movement in early childhood is increasingly being acknowledged by educators, health professionals, and government departments worldwide. In New Zealand this is best exemplified with the Ministry of Health's *Healthy Eating-Healthy Action Implementation Plan* that identified the promotion of "nutrition, physical activity and obesity issues in preschools and schools including Kohanga Reo and Kura Kaupapa Maori" as a key issue requiring initial attention (Ministry of Health, 2004, p. 17). Sport and Recreation New Zealand (SPARC) has also identified the early childhood years as an important time to address PA promotion with their launch of the Active Movement initiative in 2004. This initiative is "designed to improve the quality, accessibility, and level of participation in physical activity for all children and young people in New Zealand" (Sport and Recreation New Zealand, 2005, p. 9). The tripartite Memorandum of Understanding signed in 2004 by SPARC, the Ministry of Health, and the Ministry of Education to encourage "children to be more active and make healthy choices" (Sport and Recreation New Zealand, 2005, p. 9) is further evidence of the New Zealand Government's prioritisation of PA in childhood.

Before moving forward with these goals, it is imperative to gather a sound knowledge-base from which to guide and inform decision making processes and interventions, and to consider what the practical implications of this knowledge may be for educators and health promoters alike. Accordingly, this paper provides a review of the current state of knowledge regarding the benefits and determinants of PA. Barriers to activity are also explored, with a particular focus on the New Zealand early childhood education context. The implications of these findings for early childhood researchers, educators, and health promoters are also discussed.

Method

Findings from the *Active Movement Scoping Exercise and Programme Evaluation* report (Kolt et al., 2005) formed the basis of this paper. Relevant information has been drawn from the report, which has been built upon, updated, and summarised. Computer database searches (MEDLINE, PsychInfo, Cinahl, Eric) and manual searches were conducted of articles in the English language literature from 1970 to 2006. Reference lists were also scanned for relevant literature. Inclusion criteria were as follows: a) subjects included children aged less than 5 years, and b) PA and/or concepts relating to PA were the literature focus. In line with Sallis, Prochaska and Taylor (2000) articles were excluded that had a primary focus on sports participation, laboratory studies, case studies, expert opinion, and book chapters. Because of the paucity of research in this area, a second tier of literature was searched, encompassing doctoral dissertations and websites of national and international education associations, universities, and government departments. The studies reviewed consisted of pre-school or community samples, used a variety of outcome measures and research designs, and are briefly outlined in Table 1. The terms 'young child', 'early child', and 'pre-school' refer to children aged less than 5 years, 'child' refers to school-aged children, and 'adolescent' refers to children aged 13 years and over.

TABLE 1. Descriptive Characteristics of Physical Activity and/or Obesity Studies in Early Childhood Populations

Study	Sample	Ages	Measures	Results
Berenson et al. (2002)	US; cohort study of 16,000 individuals	0 at baseline (1973), now aged 38y	BMI, BP, extensive CVD risk factor profiling	CVD risk factors are exhibited in early childhood & are predictive of adult CVD risk; an upward secular trend in childhood obesity has occurred
Boldemann et al. (2006)	Sweden; 197 children	4-6y	BMI, UV radiation, ECE outdoor environment, environmental conditions	Quality of ECE outdoor environment (more trees, shrubbery etc.) was associated with increased PA and reduced UV radiation
Carter et al. (2005)	NZ; 240 children	3y	BMI, WC, 5 days accelerometry	25% of children were owt or obese; significant variation in PA levels between children was found
Dennison et al. (2002)	US; 1405 boys, 1356 girls	2-4y	BMI, TV watching, TV accessibility, maternal BMI, maternal education	OR of children being owt was 1.06 for each h/day of TV/video watching; nearly 40% had a TV in their bedroom & these children were more likely to be owt & watch more TV
Dowda et al. (2004)	US; 125 boys, 141 girls	3-5y	Centre policies, practices and quality; direct observation of PA	Quality of ECE centre was associated with less sedentary activity and higher MVPA
Finn et al. (2002)	US; 106 boys, 108 girls	3-5y	BMI, 2 days accelerometry, parental BMI & education, prematurity, participation in organised activities	Sex, prematurity, childcare centre attended, and paternal BMI influenced children's PA
Fisher et al. (2005)	Scotland; 394 children	4.2 ± 0.5y	BMI, FMS, <6 days accelerometry	Habitual PA was weakly associated with FMS

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Gillis et al. (2006)	Canada; 80 boys, 117 girls	4-16y	BMI, 7-day PA recall	PA was negatively associated with BMI; girls were less active than boys; owt and non-owt children aged 4-7y had similar PA profiles; owt children had more sedentary activity
Gordon et al. (2003)	NZ; 21 boys, 20 girls	3-7y	BMI, FM, FFM, %BF, skinfolds, circumferences	34-49% of children were obese (depending on criterion); over 60% had truncal fat levels exceeding scores for NZ children
Gustafson et al. (2006)	Review of 34 international studies	3-18y (various studies)	Parental correlates of PA (various measures)	Significant correlations were found for parental support and child PA
Hancox et al. (2004)	NZ; 535 boys, 502 girls at baseline	3y at baseline, followed up at 5, 7, 9, 11, 13, 15, 18, 21, & 26yrs	BMI, BP, VO2 max, blood cholesterol, TV watching	Average weeknight TV viewing between 5-15y was associated with higher BMI, lower fitness, & raised cholesterol at 26y; in 26y individuals, 17% of owt, 15% of increased cholesterol, & 15% of poor fitness was attributed to watching TV for >2h daily
Hernandez et al. (1998)	US; 144 boys, 165 girls	3-6y	BMI, teacher reports of child behaviours & health screening tests	32% of children were obese; owt & obese children are more likely to develop risk factors for CVD & diabetes
Janz et al. (2001)	US; 179 boys, 189 girls	4-6y	BMC, BMD, 4 days accelerometry, parental report of child's usual PA & TV watching	PA was associated with BMC & BMD; VPA had strongest relationships with bone health
Janz et al. (2002)	US; 217 boys, 250 girls	4-6y	BMI, %BF, FM, FFM, TV watching, 3-4 days accelerometry	Low VPA and high TV watching were associated with fatness
Janz et al. (2004)	US; 218 boys, 249 girls	4-7y	Bone geometry, 3-4 days accelerometry, PA questionnaire	Habitual PA was associated with improved bone geometry

Khoury et al. (2004)	US; 247 children	2-4y	BMI, FM, FFM, BMD, accelerometry	PA was associated with LBM and BMI
Klesges et al. (1990)	US; 122 boys, 100 girls	3-6y	BMI, direct observation of PA	PA was associated with parental weight status, % time spent outdoors, and child's relative weight
Lucas et al. (2006)	NZ; 78 children	3-5y	BMI, >18h accelerometry, EC environment	PA was moderately associated with indoor space; hourly PA had a weak negative association with outdoor space; 76%, 18%, and 6% of time was spent sedentary, in light PA, & in MVPA, respectively
McKenzie et al. (2002)	US; 104 boys, 104 girls	4y at baseline, then 5y, 6y, & 12y	Movement skills, 7-day PA recall	No significant association between motor skills in early childhood and PA at 12y
Moore et al. (1991)	US; 63 boys, 37 girls	4-7y	8.6 ± 1.8 days accelerometry, parental PA	Children of active mothers and fathers were 2.0 and 3.5 times as likely to be active as children of inactive parents respectively; children from families with 2 active parents were 5.8 times more likely to be active than those with 2 inactive parents
Moore et al. (2003)	US; 63 boys, 40 girls	3-5y at baseline, followed up for 8y	BMI, skinfolds, 3-5 days accelerometry	More active children had significantly smaller gains in BMI and skinfolds
Pate et al. (2004)	US; 115 boys, 132 girls	3-5y	BMI; 1-11 days accelerometry	The pre-school a child attended significantly predicted VPA and MVPA; boys had more VPA and MVPA than girls
Poest et al. (1989)	US; 269 boys, 245 girls	Age not stated, children attending	Parental and teacher report of child's PA	Children were not engaged in VPA year round; parental PA correlated with child PA;

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		early childhood centres		teacher education level was associated with instructional time spent for motor development
Proctor et al. (2003)	US; 73 boys, 40 girls	3-5y at baseline, followed up annually to 12y	BMI, skinfolds, % calories from fat, protein, & carbohydrate, TV watching, parental BMI & PA	Children who watched the most TV during childhood had the greatest increase in body fat over time
Reilly et al. (2005)	UK; 3934 boys, 3824 girls	0y at baseline, followed up regularly to 7y	BMI at 7y, TV watching at 3y, birth weight and weight gain profiles, parental BMI, sleep hours	Parental BMI, early BMI/adiposity rebound, >8h TV watching per week at 3y, catch-up growth, weight gain in first year, birth weight, per 100g, & <10.5h sleep duration at 3y were associated with increased risk of obesity at 7y
Reilly et al. (2006)	UK; 273 boys, 272 girls	4.2 ± 0.5y at baseline	BMI, 6 days accelerometry, FMS	No change in PA or BMI at 6 or 12m post PA intervention; significant increase in FMS in intervention group
Robinson et al. (2006)	US; 42 boys, 38 girls	4-7y	BMI, TV viewing time (allowance monitor & parental report)	Children with TV in bedroom watched significantly more TV
Roemmich et al. (2006)	US; 32 boys, 27 girls	4-7y	BMI, 4 days accelerometry, neighbourhood environment, TV viewing time (allowance monitor)	Sex, age, socioeconomic status, adiposity, and TV watching explained 14% of the variance in PA, housing density a further 12%, and percentage of park plus recreation area a further 10% of PA variance

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Sääkslahti et al. (1999)	Finland; 50 boys, 55 girls	3-4y	BMI, CVD risk factors, weekend PA, FMS	PA was weakly associated with FMS and negatively associated with CVD risk factors; outdoor play and MVPA were strongest predictors of improved outcomes
Sääkslahti et al. (2004)	Finland; 82 boys, 73 girls	4-5y at baseline, followed up for 3y	BMI, BP, serum total & HDL cholesterol, HDL/total cholesterol ratio, triglyceride concentration, PA diary	High PA was associated with reduced trigycerides, especially at 6y; girls' PA level was associated with improved cholesterol and triglyceride profiles at 6y; outdoor play in boys was related with improved cholesterol profiles at 4y
Sallis et al. (1988)	US; 13 boys, 20 girls	3-5y	BMI, direct observation, parental BMI, parental self-reported PA, family CVD risk	Children spent 58% of time in sedentary activities; family CVD risk, parent VPA, and paternal BMI was associated with children's PA
Sallis et al. (1993)	US; 328 families	4.4 ± 0.5y	BMI, skinfolds, social and home environment, direct observation of PA	Time spent outdoors and prompts to be active were associated with increased PA
Sallis et al. (2000)	Review of 108 international studies	Studies were categorised by age (either "children" aged 3-12y, or "adolescents" aged 13-18y)	Various measures of PA, and socio-environmental correlates of PA	Boys were more active than girls; for children aged 3-12y, PA preferences, intention to be active, perceived barriers (inverse), previous PA, healthy diet, program/facility access, time spent outdoors, and parental BMI were associated with PA level

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Scantling et al. (2005)	US; 48 boys, 52 girls	4-7y	BMI, %BF, FM, FFM, 6 days accelerometry	Moderate PA & MVPA was inversely associated with body weight in girls; children in the highest tertile for MVPA weighed significantly less and had 20% less fat mass than children in the least active tertile
Sibley & Etnier (2003)	Meta analysis of 44 international studies	Studies classified by age groups (4-7y, 8-10y, & 11-13y)	Various cognitive and PA assessment measures	Larger effect sizes were found for PA and cognition in 4-7y children than the 11-13y children
Specker & Binkley (2003)	US; 178 children	3-5y	BMC, 3-day diet, 2 days accelerometry	PA was associated with BMC, which was more pronounced with calcium supplementation
Specker et al. (1999)	US; 72 infants	6m at baseline, followed up at 9, 12, 15, & 18m	BMC, 3-day diet, PA	PA was associated with BMC only in the presence of adequate calcium intake
Trost et al. (2003)	US; 118 boys, 127 girls	3-5y	BMI, direct observation, 1-11 days accelerometry	Overweight boys were significantly less active than non-overweight boys
Vaska & Volkmer (2004)	Australia; 114,669 children	4y	BMI	Rates of overweight and obesity in children increased significantly from 1995–2002; in 1995 12.8% and 10.2% of females & males were overweight or obese respectively, in 2002 21.4% and 17.3% of females & males were overweight or obese, respectively

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Vásquez et al. (2006)	Chile; 12 boys, 12 girls	3-5y	FFM, FM, 3 days accelerometry, EE, energy intake	PA was negatively associated with body fat; sedentary activity was higher in day care compared with the home environment
Voss et al. (2003); Wilkin et al. (2004)	UK; 170 boys, 137 girls	5y (Year 1 at school, mean age 4.9y)	BMI, 7 days accelerometry, diet, insulin resistance, blood profiles	No information on any relationship between PA and insulin resistance has been reported to date
Worobey et al. (2004)	US; 16 boys, 26 girls	4-5y at baseline, followed up for 1y	BMI, BP, 1-day accelerometry	48% were owt or obese; EE was associated with BMI

BF = Body fat; BMC = Bone mineral content; BMD = Bone mineral density; BMI = Body mass index; BP = Blood pressure; CVD = Cardiovascular disease; EC = Early childhood; ECE = Early childhood education; EE = Energy expenditure; FM = Fat mass; FFM = Fat-free mass; FMS = Fundamental motor skills; h = Hours; m = Months; MVPA = Moderate-to-vigorous physical activity; NZ = New Zealand; OR = Odds Ratio; owt = Overweight; PA = Physical activity; TV = Television; US = United States of America; UV = Ultra-violet; VO2 max = Maximum oxygen consumption (fitness test); VPA = Vigorous physical activity; WC = Waist circumference; y = Years

Results

Physical Activity Benefits in Early Childhood

1. Overweight and Obesity

Weight gain, overweight status, and weight in infancy persists through the pre-school years (Mei, Grummer-Strawn, & Scanlon, 2003), and has been associated with overweight in later childhood and adulthood (Stettler, Kumanyika, Katz, Zemel, & Stallings, 2003). Overweight and obese school-aged children are more likely to develop risk factors for cardiovascular disease and diabetes (Hernandez, 1998), and are at much greater risk of developing adult obesity (Deckelbaum & Williams, 2001). Calculated as weight (kg) / height (m)^2, body mass index (BMI) is commonly used as an indicator of body size. Age- and sex-specific BMI cut-off points have been determined for youth aged 2-18 years that relate to overweight (25 kg/m2) and obesity (30 kg/m2) at 18 years (Cole, Bellizzi, Flegal, & Dietz, 2000). BMI is not an exact measure of adiposity, however, and so should be considered as a screening tool and for prevalence estimations only rather than as a diagnostic assessment of overweight or obesity.

A number of studies have reported a high and/or increasing prevalence of overweight and obesity in children aged less than 5 years (Gordon et al., 2003; Vaska & Volkmer, 2004), including a recent cohort study children in Dunedin, New Zealand, whereby a quarter of the 3 year old children were overweight or obese at baseline (Carter et al., 2005). Recent US

data has shown that the prevalence of obese children aged 0 to 6 years increased from 6.3% to 10.0% from 1980 to 2001, and the prevalence of overweight children increased from 11.1% to 14.4% during the same time period (Kim et al., 2006). Notably, these trends were evident for all age categories of children, including infants aged less than 6 months.

A number of cross-sectional studies have shown a negative relationship between body size (overweight, obesity, or body fatness) and PA level in young children (Khoury, Claytor, & Daniels, 2004; Trost, Sirard, Dowda, Pfeiffer, & Pate, 2003; Vásquez, Salazar, Andrade, Vásquez, & Diaz, 2006). As well, specific PA variables, such as amount of vigorous PA (Janz et al., 2002), and moderate-to-vigorous PA (Scantling, Heelan, Abbey, & Eisenmann, 2005) have been related to reduced body size in early childhood. Two studies have investigated the longitudinal relationship between PA and body size (Moore et al., 2003; Worobey, Adler, & Worobey, 2004). Children classified as 'most active' in the longitudinal Framingham Children's Study (see footnote 1) had consistently less gains in body size between 4-7 years of age compared to children classified as 'least active' (Moore et al., 2003). Nutritional intake was controlled for in the analyses, and energy intake actually increased with increasing PA level. Conversely, no difference was found between PA and weight classifications over time in another sample of US pre-school children (Worobey, Adler, & Worobey, 2004). Interestingly, no relationship between energy intake and body size was found in the latter study, indicating that there may be confounding factors influencing the relationships between body size, nutrition, and PA. One randomised controlled trial has been conducted in an attempt to increase PA and reduce obesity in pre-school children (Reilly et al., 2006). The intervention comprised a 30-minute PA programme three times per week for 24 weeks (delivered by nursery staff), and provision of materials to families promoting PA and reduced TV time. Six- and 12-month follow-up measurements showed no significant difference in PA level, sedentary behaviour or BMI as a result of the intervention. Accordingly, more comprehensive intervention may be required to improve PA levels and any subsequent influence on weight status. The longitudinal association between PA and body size requires further investigation to determine whether PA influences weight status or vice-versa, and to ascertain how much PA is required for healthy weight maintenance, while also accounting for other contributing factors to excess body size.

Inactivity has also been associated with overweight and obesity in early childhood. It is important to note that inactivity is not the exact inverse of PA. Rather, PA and inactivity are independent variables that can both have an effect on health outcomes (e.g., obesity prevalence) (Dietz, 1996). This is because inactivity is often described and quantified as a behaviour (e.g., watching TV), rather than as a reduced PA level (e.g., Gillis, Kennedy, & Bar-Or, 2006), and these behaviours have been associated with unhealthy activities such as increased consumption of fatty foods (Dietz, 1996). Objectively assessed TV watching (using TV allowance monitors) has actually been positively associated with accelerometer-determined PA in young children (Roemmich et al., 2006), demonstrating the ambiguous relationship between these variables.

Study findings have varied, but in general, screen time exposure (TV, video/dvd, computer, and/or game console use) of more than 2-3 hours daily has been associated with an increased risk of being overweight or obese in young children. For example, Reilly et al. (2005) found that, compared with children who watched under 4 hours of TV weekly, children who watched between 4-8 hours or more than 8 hours of TV per week were 1.37 and 1.55 times more likely to have BMI values categorised as overweight or obese, respectively. Dennison et al. (2002) established that, for every additional hour of TV/video watching per day, pre-school children were 1.06 times more likely to be categorised as overweight or obese by BMI. In the same study, children who had a TV in their bedroom were 1.31 times more

likely to be in overweight or obese than children without a bedroom TV. Unsurprisingly, recent research using TV allowance monitors has also shown that 4-7 year old children with a bedroom TV accumulate significantly more TV-watching time than children without a TV in their bedroom (Robinson et al., 2006).

Using a more robust measure of body size than the latter studies, Janz et al. (2002) found that percentage of body fat was significantly associated with time spent watching TV. Recently, Gillis et al. (2006) also found that overweight children (categorised by percentage body fat) spent significantly more time using the computer, TV, or video games than their normal weight counterparts. Only one study, the Framingham Children's Study, reported the longitudinal influence of TV watching in early childhood on body size (Proctor et al., 2003). Findings showed that at 11 years of age, children who had watched more than 3 hours of daily TV during early childhood had significantly higher BMI, triceps skinfold, and sum of five skinfolds. Only one New Zealand study has been published that has assessed TV time and body size in children (Hancox, Milne, & Poulton, 2004). Although this relationship was assessed in participants aged 5 years and older, the New Zealand sample and longitudinal nature of the study make it worthwhile reporting. Study findings showed that increased TV weeknight watching between 5-15 years was significantly associated with BMI. In addition, the authors estimated that 17% of overweight in the sample at 26 years could be attributed to watching TV for more than 2 hours daily during childhood and adolescence.

Collectively, the above studies provide strong evidence for the positive relationship between parent-reported screen time and body size in pre-school children. This is an area for concern, particularly considering that physical inactivity has been shown to track even more strongly than PA from late childhood to early adulthood (Raitakari et al., 1994). A majority of studies found were cross-sectional and used BMI as an indicator of body size. Further studies are required to longitudinally and objectively quantify time spent being sedentary and investigate the link between screen time, sedentary time, nutritional practices, socio-environmental factors, and more sensitive measures of body size. The application of proxy reports of sedentary behaviours to date are likely to result in bias. Ideally, future research should aim to utilise objective measures of sedentary behaviour, such as accelerometry and TV allowance monitors. Although the population-wide quantification of the prevalence of participation in PA and inactivity is fundamental to understanding the role of PA in the health of young children's lives, this is an area that has not yet been explored.

2. Cardiovascular Disease and Type 2 Diabetes

Both cardiovascular disease and type 2 diabetes are often intrinsically linked with increased body fatness, a phenomenon termed the 'metabolic syndrome'. Individuals with this syndrome exhibit indicators of cardiovascular disease (e.g., increased blood pressure, cholesterol, low density lipoproteins, and triglycerides), diabetes (insulin resistance), and body fatness (Voss et al., 2003). While cardiovascular disease and type 2 diabetes are normally exhibited in adult populations, cardiovascular risk factors have been shown to begin in early childhood and be predictive of cardiovascular risk in adulthood (Berenson, 2002). Increased insulin sensitivity has also been observed in young children at 4.9 years of age (Wilkin et al., 2004).

To date, no published literature has reported the relationship between PA and type 2 diabetes in pre-school children. The Special Turku Coronary Risk Factor Intervention Project for Babies (STRIP) (see Footnote 2) has assessed the relationship between coronary heart disease risk factors (BMI, cholesterol concentrations and ratios, blood pressure, triglycerides) and parent proxy-reported PA in young children aged 4 years at baseline (Sääkslahti et al., 2004). A negative relationship between trigycerides and high PA levels

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was found, especially when the children were aged 6 years. Results were also differentiated by gender – in girls a higher PA level was associated with improved cholesterol and triglyceride profiles at 6 years, whereas in boys, playing outdoors was related with improved cholesterol profiles at 4 years. This large cohort study employed in-depth objective measures of cardiovascular risk factors, but the use of proxy-report methods to assess PA is a limitation.

While there is evidence that young children may exhibit indicators of cardiovascular disease, type 2 diabetes, and the metabolic syndrome, there is a dearth of information relating to the relationship between PA and these lifestyle diseases in early childhood. Further research in this area is required before definitive conclusions can be drawn.

3. Bone Health

It is now well known that being active is related to the development and maintenance of healthy bones across the lifespan. The majority of the benefit is due to the forces applied to bone during activity, whereby mechanical loading causes adaptive bone responses resulting in improved bone density (Anderson, 2000). Achieving a peak bone density prior to puberty is integral to determining bone health (and reducing the risk of osteoporosis) in later life (Anderson, 2000).

Participating in gross motor activities (bone loading) has shown greater improvements in bone mineral density than fine motor activities (non-loading) in infants (Specker, Mulligan, & Ho, 1999) and toddlers aged 3-5 years (Specker & Binkley, 2003), however, this benefit was only observed in the presence of adequate calcium intake. The first study to investigate the influence of objectively measured habitual PA (using accelerometers) on bone density in young children was the Iowa Bone Development Study (see Footnote 3) (Janz et al., 2001). Findings indicated that physically active young children had greater site-specific bone mass, bone mass density, and total body bone mass compared to their less active peers, and that time spent in vigorous PA was most highly associated with bone measures. In more recent research (based on the Iowa Bone Development Study), Janz et al. (2004) found that bone adapted positively to increased loading during daily accelerometer-determined PA in children aged 4-7 years. Importantly, this increase in bone strength was achieved through 'everyday' activity rather than specific bone loading activities or elite sport performance. A primary limitation of the latter two studies was the absence of assessment of calcium intake in the participants.

The above studies provide cumulative evidence for a positive relationship between objectively assessed PA variables (vigorous PA, everyday/habitual PA) and bone health in young children. This relationship may be attenuated somewhat by calcium intake, and therefore any future related studies must take this variable into account.

4. Motor Skill Development

Fundamental motor skills comprise the basic skills (e.g., jumping, hopping, skipping, throwing, catching) that provide the foundation for more complex movement patterns. The development of fundamental motor skills results from a dynamic interaction between the growing and maturing child, their environment, and the task requirements of physical activities performed by that child (Malina, 2004). A basic mastery of these skills in early childhood has been cited as a key factor in lifelong participation in PA, recreational pursuits, and/or sports (Booth et al., 1999).

In their study of children aged 3-4 years, Sääkslahti et al. (1999) found only a weak association between PA and fundamental motor skills; however, PA was assessed

subjectively with a proxy-report diary completed by parents. More recently, Fisher et al. (2005) investigated the relationship between objectively measured PA (using 6 days of accelerometry) and fundamental movement skills. Findings showed significant positive relationships between fundamental motor skill development and both total PA and percentage of time spent in moderate-to-vigorous PA. The study of Reilly et al. (2006) also reported improved fundamental movement skills in pre-school aged children as a result of a 24-week PA intervention, although no significant change in accelerometer-determined PA was found. While evidence exists for a positive relationship between PA and fundamental motor skill development, further work is required to understand this relationship and to establish whether PA promotes fundamental motor skill development, or vice-versa.

Increased PA may be related to fundamental motor skill development in early childhood. This relationship is still not well understood as cross-sectional study designs and self-reported PA measures have been commonly applied in this area. More research is required to assess this relationship over time, to determine whether PA influences level of motor skill development, or vice-versa.

5. Cognitive Functioning

Improved cognitive functioning has also been suggested as a benefit of PA in early childhood (Leppo, Davis, & Crim, 2000; Pica, 1997). Developmental biology has provided an insight into environmental influences (including some forms of movement) on the developing brain architecture in early childhood (Leppo, Davis, & Crim, 2000; National Scientific Council on the Developing Child, 2005), with physiological changes in the brain and developmental and learning changes occurring in response to activity (Sibley & Etnier, 2003). Activities that require crossing of the midline have been promoted as being particularly important to activate both brain hemispheres in a balanced way (Hannaford, 1995). No research has yet been published that has investigated cognitive development and objectively measured PA in children aged less than 5 years, and so this relationship is still not well understood.

Physical Activity Patterns and Correlates in Early Childhood

Exactly how much activity, and what type of activities, are required for health benefits in young children are yet to be fully determined. As well, our understanding of how active (or inactive) young children actually are is limited. A number of small studies have objectively quantified the PA levels of children using accelerometers, pedometers, and other motion sensors which have provided some indication of the PA patterns of this population, and are outlined in Table 1. Significant differences in PA can already be observed in children younger than 5 years, with the following shown to be positively related to one or more PA variables: male gender (Pate, Pfeiffer, Trost, Ziegler, & Dowda, 2004), full term birth (Finn, Johannsen, & Specker, 2002), outdoor play time (Sääkslahti et al., 1999), the family environment (Gustafson & Rhodes, 2006), quality of early childhood education setting (Finn, Johannsen, & Specker, 2002; Pate, Pfeiffer, Trost, Ziegler, & Dowda, 2004), and neighbourhood environment (Roemmich et al., 2006).

The studies of Finn et al. (2002) and Pate et al. (2004) provided convincing evidence for the importance of early childhood education environments in encouraging PA, with the pre-school centre setting being the strongest individual predictor of PA in their samples. Specific education setting variables such as amount of time spent outdoors, quality of outdoor environment (Boldemann et al., 2006; Sallis, Prochaska, & Taylor, 2000), staff qualification level (Dowda, Pate, Trost, & Sirard, 2004), and overall centre quality (Dowda, Pate, Trost, & Sirard, 2004) have been associated with increased PA in young children.

The family environment also appears integral to encouraging PA in early childhood. Parental variables such as prompting and encouragement for their child to be physically active (Sallis et al., 1993), parental PA level (Moore et al., 1991; Poest, Williams, Witt, & Atwood, 1989), parental vigorous PA (Sallis, Patterson, McKenzie, & Nader, 1988), and a lower parental BMI (Finn, Johannsen, & Specker, 2002; Klesges, Eck, Hanson, Haddock, & Klesges, 1990) have been related to the PA level of their pre-school child. The first study to consider the built environment in relation to PA in young children showed that increased proximity between homes (density) and a greater proportion of park area in the neighbourhood was related to increased PA in their sample of 4-7 year old children, even after controlling for sex, age, family socioeconomic status, overweight status, and TV watching time (Roemmich et al., 2006). Unique strengths of the latter study were the utilisation of a combination of objective measurement and analysis tools such as accelerometers, TV allowance monitors, and spatial mapping software.

New Zealand Research

To date, there are two studies that have objectively investigated PA in New Zealand pre-schoolers (Carter et al., 2005; Lucas & Schofield, 2006). The FLAME study is a 4 year investigation of the risk factors for obesity in 3 year old Dunedin children (Carter et al., 2005). This study has assessed PA using accelerometers over 5 days and will also investigate sedentary behaviour and family attitudes towards activity and nutrition. Baseline findings showed considerable variation in PA levels between children which were not associated with gender; however, follow-up assessments have not yet been conducted so it is unclear whether this is an age-related finding. Data collection will occur annually for the next 3 years with the aim of identifying specific factors related to excessive weight gain in young children to inform intervention development. Another study focused on PA patterns and environmental factors that may be related to PA in Auckland children aged 3-5 years utilising accelerometers (Lucas & Schofield, 2006). Associations between PA (sedentary, light, moderate-to-vigorous PA) and early childhood education setting environment variables (space and furnishings, programme structure, activities) were determined. Indoor space was moderately associated with increased accelerometer counts per hour and total counts, while outdoor space had a weak negative association with accelerometer counts per hour. Lucas and Schofield (2006) suggested these differing activity levels based on indoor and outdoor space may have been related to scheduled activities within the education settings. Interestingly, inactivity accounted for 76% of the time measured, with 18% of time spent in light activity, and only 6% in moderate-to-vigorous PA. These findings provide evidence for the potentially significant role inactivity may play in young children's lives, and the importance of investigating sedentary time further.

While both of the above studies are important in contributing to the New Zealand evidence base of PA research in early childhood, there still remain a number of unanswered questions. For example, the FLAME study is measuring parental attitudes towards PA, however, this is a subjective assessment that will not provide any objective evidence of the parental role in their pre-school child's PA behaviours. Further, a monitoring period of 5 days may be inadequate to provide an accurate assessment of PA in this population (Sirard, Trost, Dowda, & Pate, 2001). Similarly, the Lucas and Schofield (2006) study involved PA monitoring over 5 pre-school days only, and no assessment of weekend PA or PA outside the pre-school environment was assessed. Neither of the New Zealand studies assessed the relationship between the neighbourhood built environment and PA in early childhood. Consequently, more in-depth data collection of PA patterns and potential correlates of PA in New Zealand pre-schoolers is required, to add to, and improve on, the current state of knowledge in this field. The primary author is currently embarking on a cross-sectional

study with children aged 3-5 years in an attempt to answer some of these questions. The study will measure PA in young children and one or both of their parents using accelerometers over 7 full consecutive days. Measures of potential socio-environmental correlates of children's' PA will be assessed using a questionnaire (e.g., number of televisions in household), and perceptions about parental and child PA levels will be assessed. This will be the first study in New Zealand (and only the second study worldwide), to investigate the relationship of objectively determined PA in children aged less than 5 years in relation to their built neighbourhood environment using spatial mapping. Aims of the study are to: quantify and describe in detail the PA and inactivity of 3-5 year old Auckland children and their parents; determine the relationships between PA, inactivity, and weight status; and to identify social and environmental factors that can be targeted for intervention.

Barriers to Activity Participation and Promotion in Early Childhood

A number of researchers have conducted qualitative research to identify barriers to the encouragement of PA and PA participation in young children via focus groups and interviews with parents, educators, health professionals, and government representatives (Goodway & Smith, 2005; Irwin, He, Bouck, Tucker, & Pollett, 2005; Kolt et al., 2005; O'Connor & Temple, 2005). Results have been consistent amongst studies and participants, with overwhelming agreement that PA is important in early childhood, for physical, psychological, and social wellbeing and development. While the importance of PA was acknowledged, reports of active encouragement of young children to be physically active or participating in PA with children were minimal. A number of reasons for this phenomenon were proposed by the participants of these studies, as follows: 1) some felt that children were sufficiently active without any need for further prompting or encouragement; 2) there was insufficient space, and/or a lack of covered outdoor area, for PA in the home or centre environment; 3) caregivers and educators reported lacking confidence, skills and/or knowledge required to promote PA; 4) there was a lack of logistical support for PA promotion, in terms of appropriate teacher education and funding for equipment; and 5) government regulations (noise limitations, playground safety) and centre policies (rules regarding types of activities performed indoors and outdoors, restricted planning for PA, access to TV, scheduled outdoor time, policies regarding outdoor excursions) significantly limited opportunities for PA promotion. As well, parents reported insufficient time, perceived lack of neighbourhood safety (road safety and 'stranger danger', especially in underserved communities), expense of structured programmes, lack of community role models, and children's preferences for sedentary activities as key barriers to PA in early childhood.

Especially pertinent to the New Zealand context, findings from consultation with stakeholders in early childhood education and health (early childhood and tertiary educators, government representatives, health promoters, parents, researchers) for the *Active Movement Scoping Exercise and Programme Evaluation* showed that people and general society were fundamental barriers to PA promotion and encouragement in early childhood (Kolt et al., 2005). At the macro level, societal attitudes towards prioritisation of academic learning and achievement over play and PA, and a general culture shift towards inactivity and a preference for sedentary pursuits were identified as constraints to promoting activity in young children. Limited information and support for early childhood educators was highlighted, particularly in terms of pre-service and in-service professional development, and to a lesser degree, funding for equipment and training. While a number of programmes were identified that facilitated PA in early childhood education settings, these programmes were not being rigorously evaluated, nor were they being efficiently disseminated

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throughout the early childhood community. At an individual level, the attitudes, behaviours, knowledge and available time of both parents and early childhood educators were identified as key barriers to PA promotion. Specifically, parental prioritisation of academic (literacy and numeracy) learning outcomes and less regard for the potential learning opportunities and social and holistic benefits gained from PA posed a considerable challenge for early childhood educators. Concurrently, educators themselves felt ill-equipped to promote PA appropriately, and many reported being inactive themselves.

Summary and Implications

PA may confer a multitude of benefits to the young child. There is sufficient evidence to suggest a negative relationship between PA and body size, and strong evidence for a positive association between sedentary activity and body size in early childhood. PA has also been associated with improved bone density in young children, particularly in the presence of adequate calcium intake. A positive relationship has been exhibited between PA and fundamental motor skill development in toddlers.

A number of questions remain unanswered. There is a dearth of research investigating the interactions between PA and cognitive development, insulin resistance, and cardiovascular disease risk factors in early childhood. The influencing variables in the relationships between PA and health outcomes need to be determined in longitudinal research, and whether these relationships track over time is yet to be established. Understanding the overall prevalence of PA and sedentary behaviours in young children is essential. Future research is necessary to objectively quantify time spent being physically active and sedentary, and to investigate associations between PA, screen time, sedentary time, nutritional practices, and health outcomes in early childhood. The level of PA required for health gain in young children, and variables that can either be modified or targeted for PA intervention in this population group need to be identified.

The current state of knowledge indicates that important PA variables to assess are amount of vigorous PA and sedentary time. Family and early childhood education settings appear important environments to investigate further in terms of influencing PA and being amenable to change. More work is required to understand the influence of the built environment on PA in early childhood. Early childhood educators require ongoing logistical support to promote and encourage PA, including pre-service and in-service training, and government legislation and centre policies that encourage PA promotion and participation. Improved societal knowledge and attitudes regarding the fundamental role of PA in healthy development and learning is integral. Inter-sectoral approaches (between health, education, and researchers) and effective lines of communication are required to disseminate best practice approaches and research findings throughout the early childhood education community, and to ensure a consistent PA message is promoted. The SPARC Active Movement Initiative is an ideal means by which to meet some of these needs, particularly in terms of teacher training and societal education, advocacy, and improved communication and collaboration between agencies and disciplines.

This issue is of importance to all New Zealanders at an individual, community, and national (policy) level. Given the current dearth of robust research in this area, it is imperative that carefully conducted research to improve our knowledge and understanding of PA in the early childhood years is considered a priority area for educators and health promotion researchers in New Zealand and internationally.

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Footnotes

1. The Framingham Children's Study is a longitudinal study of determinants of nutrition and physical activity in early childhood. The study began in 1987 with 106 children aged 3-5 years from the Framingham region. Data collection has occurred on an annual basis since 1987.

2. The STRIP Study began in Finland in 1990 with the aim to curb atherosclerosis development by providing lifestyle intervention to 1062 children aged 7-36 months and their families. The intervention has continued and follow-up measurements will be conducted biannually until the children are 20 years.

3. The Iowa Bone Development Study investigated the relationship between PA and bone health in 470 children from Iowa. The Study is a sub-study of the Iowa Fluoride Study, a longitudinal study of fluoride intake and dental fluorosis of 890 families.

Acknowledgements

ABOUT THE AUTHORS

Melody Oliver is currently completing her PhD investigating physical activity and inactivity patterns in children aged 3-5 years, and the social and environmental factors that may be related to children's activity patterns. Research findings will help to inform and guide interventions and policy in health promotion and obesity prevention in early childhood.

Associate Professor Grant Schofield has expertise in health promotion, physical activity measurement, and determinants of physical activity. His research spans most groups across the lifespan from pre-schoolers to older adults as well as whole community approaches to understanding and increasing physical activity.

Professor Gregory Kolt has a background in psychology and physiotherapy and has worked extensively across research, clinical and teaching areas in these disciplines. His current research focuses on health-related physical activity, the ageing population, and physical activity interventions.

Associate Professor Claire McLachlan is the coordinator of the postgraduate programme in Early Years Education at Massey University College of Education. Claire's research interests, in addition to physical activity in young children, include early childhood education, teacher education, teachers' beliefs about curriculum, emergent literacy and open, distance and flexible learning.

Appendix H: Physical activity in preschoolers. Understanding prevalence and measurement issues

Physical Activity in Preschoolers
Understanding Prevalence and Measurement Issues

Melody Oliver,[1] *Grant M. Schofield*[1] and *Gregory S. Kolt*[1,2]

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Contents

Abstract

Accurate physical activity quantification in preschoolers is essential to establish physical activity prevalence, dose-response relationships between activity and health outcomes, and intervention effectiveness. To date, best practice approaches for physical activity measurement in preschool-aged children have been relatively understudied. This article provides a review of physical activity measurement tools for preschoolers, an overview of measurement of preschoolers' physical activity, and directions for further research. Electronic and manual literature searches were used to identify 49 studies that measured young children's physical activity, and 32 studies that assessed the validity and/or reliability of physical activity measures with preschool-aged children. While no prevalence data exist, measurement studies indicate that preschool children exhibit low levels of vigorous activity and high levels of inactivity, boys are more active than girls, and activity patterns tend to be sporadic and omnidirectional. As such, measures capable of capturing differing activity intensities in very short timeframes and over multiple planes are likely to have the most utility with this population. Accelerometers are well suited for this purpose, and a number of models have been used to objectively quantify preschoolers' physical activity. Only one model of pedometer has been investigated for validity with preschool-aged children,

showing equivocal results. Direct observation of physical activity can provide detailed contextual information on preschoolers' physical activity, but is subjective and impractical for understanding daily physical activity. Proxy-report questionnaires are unlikely to be useful for determining actual physical activity levels of young children, and instead may be useful for identifying potential correlates of activity. Establishing validity is challenging due to the absence of a precise physical activity measure, or 'criterion', for young children. Both energy expenditure (EE) and direct observation have been considered criterion measures in the literature; however, EE is influenced by multiple variables, so its use as a physical activity 'criterion' is not ideal. Also, direct observation is inherently subjective, and coding protocols may result in failure to capture intermittent activity, thereby limiting its utility as a physical activity criterion. Accordingly, these issues must be taken into account where EE or direct observation are used to validate physical activity instruments. A combination of objective monitoring and direct observation may provide the best standard for the assessment of physical activity measurement tools. Ideally, the convergent validity of various physical activity tools should be investigated to determine the level of agreement between currently available measures. The correlational approaches commonly employed in the assessment of physical activity measures do not reveal this relationship, and can conceal potential bias of either measure.

Regular participation in physical activity has been clearly established as being integral to health and wellbeing in school-aged children. There is evidence that obesity,[1,2] inactivity[3] and physical activity[4] may all track from childhood to adolescence and adulthood, and thus recent research has begun to focus on the importance of physical activity in the preschool years (<5 years). The limited evidence available suggests that increased physical activity in preschoolers is associated with a reduced risk of being overweight or obese[5-7] and less likelihood of having one or more risk factors for cardiovascular disease.[8] Improved bone health[9,10] and fundamental motor skill development[11] have also been associated with higher levels of physical activity in this population. Conversely, higher levels of inactivity in preschool-aged children have been related to an increased risk of being overweight or obese.[12-14]

Dose-response relationships between physical activity and health risk factor reduction for young children are yet to be determined. Also, the actual prevalence of physical activity participation in young children is not well understood, either at a cross-sectional or population level. There is a paucity of comprehensive information regarding the amount of habitual physical activity that young children accumulate, the types and intensities of activity participated in, and time spent in sedentary pursuits. The underlying issues facing researchers trying to understand both prevalence and dose-response relationships are based on being able to measure amounts and types of physical activity that young children engage in. Researchers require a robust, reliable and valid method, which is recognised as being 'best practice'. In practical terms, the greatest challenge is identifying what to measure, how to define what is measured, and how to ensure consistency across studies. For example, recent approaches for young children have included measuring physical activity in time, energy expenditure (EE) per unit of time, frequency of activity (activity counts), step counts, heart rate, oxygen consumption ($\dot{V}O_2$), carbon dioxide production, or other methods combining some of these units.

The purposes of this article are to review methods used to assess physical activity in young children (<5 years) and to suggest directions for future re-

search. Understanding physical activity measurement in preschoolers is essential as this provides the basis for examining health benefits of activity in this population, setting physical activity recommendations, gathering prevalence data and establishing intervention efficacy. The terms 'young child', 'preschool' and 'early childhood' have been used interchangeably to refer to children aged <5 years. Where necessary, the review has been widened to consider youth in general with a goal of understanding, by employing a more extensive database, the range of measures that might be appropriate to this younger population.

A novel approach to categorising physical activity measurement tools is used. In the literature, the term 'criterion measure' has generally been used to refer to tools that are considered exact indicators of physical activity engagement.[15] This concept is problematic, as currently none of the measures classified as a physical activity 'criterion' in the preschool literature can be considered precise assessments of physical activity. Hence, rather than dichotomising measures as either being 'criterion measures' or not, we suggest the following categories to describe tools that might be used for validating physical activity measures (in order of most to least specific): (i) objective measures of physical activity; (ii) subjective measurements of physical activity; and (iii) methods of EE calculation. Motion sensors (monitors worn by the participant that collect information on body movements) are considered objective measures of human physical activity. While EE is undisputedly a consequence of physical activity participation, this construct has been considered as a separate variable to physical activity in the current article, and a justification is provided for this in section 3.

Computer searches (MEDLINE, PsycINFO, Cinahl, Eric) and manual searches were conducted of articles in the English language literature from 1980 to 2007. Keywords included 'early childhood', 'measure', 'movement', 'physical activity', 'preschool', 'reliability', 'young child', 'valid'. Search terms included a combination of keywords, for example 'physical activity' AND ('preschool' OR 'young child' OR 'early childhood') AND ('measure' OR 'valid' OR 'reliability'). Because of the limited published literature in this field, broad inclusion criteria were applied as follows: (i) subjects were aged <5 years; and (ii) subjects' physical activity and/or the measurement tool was assessed or reported. In contrast to the earlier review of children's physical activity measurement by Sirard and Pate,[15] all validation studies have been included, irrespective of the comparison measure used. With respect to age, studies were considered if their sample included both preschool children and children aged ≥5 years. No upper age cut-off was used. While published abstracts have been included, articles were excluded that had a primary focus on sports participation, laboratory studies, case studies, expert opinion, book chapters and dissertations.

1. Objective Measures of Physical Activity

Studies identified from the search that have assessed physical activity in children aged <5 years are summarised in table I. This table also provides an outline of the differing methodologies used to assess physical activity in preschoolers to date. Where studies have used both objective and subjective measures of physical activity, only the objective measurements have been reported, as this is likely to yield the most accurate information on physical activity. Essentially, this is because objective measures can mitigate any potential inaccuracies resulting from self- or proxy-report bias[16] and/or bias resulting from researcher coding of physical activity[17] (see section 2 for further critique of subjective measures). As can be seen from table I, motion sensors (accelerometers and pedometers) were most frequently used to assess activity in young children (71%).

A key advantage of using motion sensors is that data collected are likely to be free from researcher bias. Other advantages include low researcher and participant burden, the ability to quantify physical activity over extended periods of time, and affordability as compared with direct observation methods. The primary disadvantage of using motion

Table I. Preschool physical activity measurement studies[a]

Study	Measurement protocol	No. of participants (gender, age)	Key activity findings
Accelerometer (ActiGraph)			
Heelan and Eisenmann[18]	≥4d, including 1 weekend day	52 girls, 48 boys; 4–7y	241.5 ± 48.8, 32.3 ± 17.1 and 273.8 ± 59.1 min/d were spent in MPA, VPA and MVPA, respectively
Cliff et al.[19]	≤7d	26 girls, 32 boys; mean 4.29y	On average, all children accumulated >60 min MVPA/d; 3.5% did not achieve >60 min MVPA on every monitoring day
Lucas and Schofield[20]	≥18h	78 children; 3–5y	76%, 18% and 6% of activity was SED, LPA and MVPA, respectively; boys were more active than girls (t = 2.56, p = 0.01)
Pate et al.[21]	1–11 weekdays	132 girls, 115 boys; 3–5y	Mean ± SD of 42.1 ± 5.8, 10.5 ± 3.2, 7.7 ± 3.1 and 1.9 ± 1.1 min/h were spent in SED, LPA, MVPA and VPA, respectively; preschool was a significant correlate of MVPA and VPA; boys had more MVPA (p = 0.01) and VPA (p = 0.001) than girls; African-American children had more VPA than Caucasian children (p = 0.04)
Trost et al.[22]	20 preschool sessions of 2.5h each	19 girls, 23 boys; 3–5y	Mean total counts, MPA min and VPA min for the 2.5h sessions were 171 100 ± 29 700, 12.4 ± 3.1 and 18.3 ± 4.6, respectively; children aged 3y had significantly less PA than children aged 4 or 5y
Kelly et al.[23]	7d	22 girls, 18 boys; 4–5y	Boys of higher socioeconomic status accumulated less total PA than boys of lower socioeconomic status (p < 0.05)
Reilly et al.[24]	2–3d at 3y; 7d at 5y	73 girls, 77 boys; 3 and 5y	79% and 76% of activity was SED, and 2% and 4% was MVPA, at ages 3 and 5y, respectively
Fisher et al.[11]	6d	185 girls, 209 boys; 3–5y	76.3%, 20.3% and 3.4% of PA was SED, LPA and MVPA, respectively; mean (±SD) accelerometer counts per minute were 769 ± 192; boys were more active than girls
Fisher et al.[25]	18.0–217.3h, week and weekend days	108 girls, 101 boys; 3–5y	74.2–79.5%, 17.0–21.7% and 2.1–4.1% of activity was SED, LPA and MVPA, respectively; seasonal differences were observed for total (p < 0.001), SED (p < 0.001), LPA (p < 0.001) and MVPA (p < 0.01)
Jackson et al.[26]	3d, including 1 weekend day, follow-up at 1y	52 girls, 52 boys; 3y at baseline; 30 girls, 30 boys at follow-up	Boys and girls had means of 777 ± 207 and 651 ± 172 counts/min at baseline, respectively; children at follow-up had a mean of 849 ± 252 counts/min (compared with 669 ± 165 at baseline); the tracking rank order correlation coefficient of total activity counts over 1y was r = 0.40 (p < 0.001); total PA increased over 1y (p < 0.001); boys were more active than girls (p < 0.001)
Janz et al.[9]	4d, including 1 weekend day	189 girls, 179 boys; 4–6y	Boys had more total PA and VPA than girls (p < 0.05)
Janz et al.[27]	4d, including 1 weekend day	231 girls, 203 boys; 4–6y	Mean (±SD) counts per minute for boys and girls were 773.6 ± 176.0 and 702.6 ± 154.8, respectively; mean (±SD) min/d of MVPA and VPA were 277.1 ± 50.8 and 31.8 ± 16.3 for boys, and 263.0 ± 48.2 and 24.6 ± 13.0 for girls, respectively; boys had more total PA, MVPA and VPA than girls (p < 0.05)
Janz et al.[10]	4d, including 1 weekend day	232 girls, 204 boys; 4–7y	Boys had 244 ± 43, 267 ± 44, and 38 ± 19 min/d of SED, MPA, and VPA, respectively; girls had 251 ± 48, 262 ± 44 and 28 ± 14 min/d of SED, MPA and VPA, respectively; boys were more active than girls (p < 0.05)

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Study	Measurement protocol	No. of participants (gender, age)	Key activity findings
Worobey et al.[28]	6.75h in fall and spring	26 girls, 16 boys; 4–5y	Non-overweight children accumulated (mean ± SD) 177 956 ± 60 714 and 250 950 ± 96 213 activity counts in fall and spring, respectively; overweight children accumulated 206 314 ± 91 301 and 250 336 ± 72 272 activity counts in fall and spring, respectively
Worobey et al.[29]	90 min	40 children; 4–5y	Average (±SD) activity counts for Head Start and University preschool children were 111 661 ± 61 235 and 279 157 ± 98 251, respectively (p < 0.0001)
Cardon and De Bourdeaudhuij[30]	4d, including 2 weekend days	76 children	Average SED and MVPA/day was 9.6h and 34 min, respectively; weekday total activity was higher than weekend activity (p < 0.001); boys were more active than girls (p < 0.05)
Kelly et al.[31]	3d at baseline, 7d at 2y follow-up	21 girls, 21 boys; mean 3.8y at baseline	80.5% and 74.1% of activity was SED, and 2.2% and 4.1% was MVPA at baseline and follow-up, respectively; percentage agreement and κ for PA, MVPA and SED from baseline to follow-up were 38% and 0.17, 41% and 0.01, and 26% and 0.21, respectively
Metallinos-Katsaras et al.[32]	4.7–7d	30 girls, 26 boys; 2–5y	61%, 35% and 4% of activity was SED/LPA, MPA and VPA, respectively; boys were more active than girls (p < 0.05); non-overweight children had significantly more very vigorous min and very active min of PA than overweight children (4.6 and 32.1 min vs 2.6 and 22.9 min, respectively; p < 0.05)
Roemmich et al.[33]	4d	27 girls, 32 boys; 4–7y	Mean counts/min for boys and girls were 779 ± 230 and 683 ± 178, respectively
Reilly et al.[34]	6d at 0 and 6mo	272 girls, 273 boys; 4y at baseline	Mean counts/min, %SED and %MVPA for intervention and control groups at baseline were 732 counts, 69.3%, and 2.6%, and 809 counts, 66.9%, and 3.0%, respectively; mean counts/min, %SED, and %MVPA for intervention and control groups at 6mo follow-up were 809 counts, 67.0%, 3.5% and 899 counts, 62.9%, and 4.1%, respectively
Accelerometer (ActiGraph); DO (OSRAP)			
Trost et al.[5]	1–11d (DO for 1h on 3d)	127 girls, 118 boys; 3–5y	Non-overweight girls and boys spent 41.6 ± 12.5% and 47.6 ± 12.7% of time in MVPA, respectively; overweight girls and boys spent 42.2 ± 12.8% and 39.0 ± 12.5% of time in MVPA, respectively
Accelerometer (Actiwatch)			
Finn et al.[35]	48h, weekdays	108 girls, 106 boys; 3–5y	Mean daily sensor counts were 263 000 ± 7000 and 285 000 ± 8000 for girls and boys, respectively; 4.5 ± 2% and 5.2 ± 0.2% of activity was VPA for girls and boys, respectively; boys were more active than girls (p < 0.001)
Finn and Ullmann[36]	3 weekdays	16 girls, 12 boys; 3–5y	No differences for temperature differences between seasons
Firrincieli et al.[37]	6–7d	33 girls, 21 boys; 3–5y	Asthmatic and non-asthmatic children accumulated 1041 and 1610 10 min bouts of continuous PA respectively, normalised over 7d period
Specker and Binkley[38]	48h at 0, 6 and 12mo	84 girls, 94 boys; 3–4y	12.1–14.0% and 4.5–5.4% of activity at baseline was MVPA and VPA, respectively; average daily counts for study groups at baseline were 259 000–297 000
Butte et al.[39]	3d	520 girls, 510 boys; 4–19y (14% were 4–5y)	Mean counts/day, %SED, %LPA, %MPA and %VPA for boys were 236 000 counts, 38%, 51%, 10% and 0.4%, respectively; for girls these values were 216 000 counts, 38%, 54%, 8% and 0.2%, respectively; boys had significantly more total PA and MPA, and significantly less LPA than girls (p < 0.05)

Table I. Contd

Study	Measurement protocol	No. of participants (gender, age)	Key activity findings
Accelerometer (Caltrac)			
Moore et al.[7,14,40,41]	3–5d annually for 7y	40 girls, 63 boys; 3–5y at baseline	Caltrac counts/h for children in the lowest, middle and highest PA tertiles were 8.5 ± 0.8, 10.2 ± 0.4 and 12.5 ± 1.2, respectively
Accelerometer (RT3)			
Khoury et al.[42]	3d	107 girls, 136 boys; 2–4y	Rest time during waking hours was negatively associated with vector magnitude per min (p < 0.05)
Claytor et al.[43]	3d	267 children, 2–4y	Weekday activity was higher than weekend activity; boys were more active than girls (p < 0.01)
Claytor et al.[44]	3d, including 1 weekend day	117 girls, 150 boys; 2–4y	Maternal leisure time PA was associated with children's activity vector magnitude/min (r = 0.13; p < 0.03)
Vásquez et al.[45]	3d including 1 weekend day	9 girls, 10 boys; 3–5y	%SED/LPA was 52%, 54% and 62% during weekend days, weekdays at home and at day-care, respectively. %MPA during weekend days and weekdays was 3% and 4%, respectively
DO (BEACHES-SCAN)			
Broyles et al.[46]	1h home, ≥30 min preschool, 12 × over 2.5y	167 girls, 184 boys; 4.4y at baseline	Children had higher PA indexes for recess than at home (0.078–0.084 vs 0.058–0.064)
Sallis et al.[47]	1h home, ≥30 min preschool/school, 10 × over 2y	167 girls, 184 boys, 4.4y at year 1	Home PA tracked more over time than preschool/school PA (r = 0.15 for single days, and r = 0.36 for 4d mean)
Elder et al.[48]	1h home, 10 × over 2y	138 girls, 153 boys; 4y at year 1	Boys and girls complied with parental prompts for PA in 60% and 59% of intervals, respectively
McKenzie et al.[49,50]	1 × recess period (~26 min at baseline, ~14 min at follow-up)	132 girls, 155 boys, 4y at baseline, 6y at follow-up	PA level increased over time (from 58.9% and 41.1% of time spent SED and in MVPA at 4y, respectively, to 52.5% and 47.5% SED and MVPA at 6y, respectively; p < 0.002)
Sallis et al.[51]	4 × 1h observations	347 children; 4y	Mean (±SD) intervals of time outdoors was 15.5 ± 15.5%; mean (±SD) kcal/kg/min (reported as PA) was 0.060 ± 0.008
DO (CARS)			
Baranowski et al.[52]	6h on ≥4d	101 girls, 90 boys; 3–4y	Overall mean PA was low (CARS level of ~2); outdoor play was associated with PA; gender, month and location accounted for 75% of variance in PA; boys were more active than girls
DuRant et al.[53]	≤4d, 6–12 h/d	101 girls, 90 boys; 3–4y	Mean PA level was highest during outside play, and lowest during the longest bout of TV watching (CARS level 2.38 vs 1.48)
DO (CARS); HR			
Jago et al.[54]	2.5–2.7h on 3 consecutive years	76 girls, 73 boys; 3–4y at year 1	88%, 62% and 60% of activity was SED, and 12%, 7% and 10% was MVPA in years 1, 2 and 3, respectively. SED in year 1 predicted PA in years 2 and 3

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Study	Measurement protocol	No. of participants (gender, age)	Key activity findings
DO (FATS)			
Sallis et al.[55]	30 min	20 girls, 13 boys; 3.9 ± 0.7y	58%, 31% and 11% of PA was SED, MPA and VPA, respectively
Klesges et al.[56]	1h	15 girls, 15 boys; 22–46mo	28%, 65% and 7% of activity was minimal, moderate and extreme, respectively; parental prompting was associated with extreme PA (p < 0.01); boys were more active than girls (p < 0.05)
DO (OSRAP)			
Dowda et al.[57]	1h × 3 weekdays	141 girls, 125 boys; 3–5y	Centre variables and policies were associated with MVPA (p ≤ 0.04); centre quality was associated with less SED (p = 0.04)
DO (SCAN-CAT)			
Eck et al.[58]	1h	83 girls, 104 boys, 3–4y	Children with one or more overweight parent had marginally more stationary PA (p = 0.07) and marginally less total PA (p = 0.06) than children with no overweight parents
Klesges et al.[59]	1h home	100 girls, 122 boys; 3–6y	Outdoor time, child relative weight, and interacting with others were positively associated with PA; parental overweight negatively associated with child's PA
Pedometer (Walk4Life)			
Carson and Ayers[60]	Not supplied	Preschool children	Mean (±SD) step counts were 44 423 ± 11 888 and 68 272 ± 22 362 for the control and intervention groups, respectively (p < 0.001)
Pedometer (Yamax SW/DW Series)			
Boldemann et al.[61]	12 weekdays	197 children; 4–6y	Developed outdoor landscape (trees and shrubbery) was associated with PA (p < 0.001); boys were more active than girls (8.8–37.2 and 8.9–30.0 steps/min, respectively; p < 0.001)
Cardon and de Bourdeaudhuij[62]	4d, including 2 weekend days	63 girls, 59 boys; 4–5.9y; ActiGraph accelerometer sub-sample of 39 girls, 37 boys; 4–5.9y	Average daily step count was 9980 ± 2605; weekday activity was higher than weekend activity (p < 0.001); 13 874 steps/day was identified as being comparable with accumulating to 60 min MVPA/day
Al-Hazzaa and Al-Rasheed[63]	3d	115 girls, 109 boys; 3.4–6.4y	Average daily step count was 6773; boys were more active than girls (p < 0.05)
Videotape (focal individual sampling approach)			
Hart and Sheehan[64]	24 × 30 sec observations over 12 weekdays	20 girls, 20 boys; 2–5y	Children had less PA in a contemporary playground setting (fixed equipment, landscaped, etc.) compared with a traditional (less structured, more movable equipment) playground

a Only studies that have assessed physical activity (as opposed to energy expenditure) have been included in this table. This table does not include studies where questionnaires were the only form of activity measurement nor those with a primary focus of validating a physical activity measurement tool.

ActiGraph = uni-axial accelerometer, previously known as the CSA 7164; **Actiwatch** = bi-axial accelerometer; **BEACHES** = Behaviors of Eating and Activity for Child Health: Evaluation System; **CARS** = Children's Activity Rating Scale; **CAT** = Children's Activity Timesampling method of observation; **DO** = direct observation; **FATS** = Fargo Activity Timesampling Survey; **HR** = heart rate telemetry; **LPA** = light physical activity; **MPA** = moderate physical activity; **MVPA** = moderate-to-vigorous physical activity; **OSRAP** = Observation System for Recording Activity in Preschools; **PA** = physical activity; **RT3** = tri-axial accelerometer; **SCAN** = Study of Children's Activity and Nutrition; **SED** = sedentary activity; **TV** = television; **VPA** = vigorous physical activity.

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sensors is the context in which physical activity occurs cannot be determined. The utility of pedometers and accelerometers for use with preschoolers is discussed further in sections 1.1–1.2.

1.1 Pedometers

Pedometers are small devices mounted at the hip, ankle, or wrist, that use mechanical motion sensors to quantify physical activity in terms of accumulated steps. These sensors are used to objectively quantify physical activity, specifically ambulatory activity. Pedometers are easy to use, do not require researcher or participant training or software, and their 'currency' of steps is easily understood by children and adults alike. During the past decade, several commercially available brands of electronic pedometers have become available, for example, the Yamax DW/SW series (Tokyo, Japan), NL2000 (New-Lifestyles Inc., Lees Summit, MO, USA), Freestyle Pacer (Camarillo, CA, USA), and Eddie Bauer Compustep II (Redmond, WA, USA). Collectively, the results of several studies have concluded that the Japanese-developed Yamax DW or SW series (200–700) and the NL2000 are the most accurate for use with adults.[65,66]

Although not primarily a pedometer validation study, Cardon and de Bourdeaudhuij[62] provided some evidence for the convergent validity of the Yamax SW-200 in 76 children aged 4–5.9 years. A significant correlation (r = 0.73) was measured between total daily steps and minutes of MVPA assessed using the MTI 7164 ActiGraph. Furthermore, a regression equation was developed to identify a value of 13 874 daily steps that was comparable with the accumulation of 60 minutes of moderate-to-vigorous physical activity throughout the day.

The earliest study to consider pedometer validity in preschoolers was that of Nishikido et al.,[67] who found that physical activity assessed with the Yamasa AM-5 pedometer was moderately to strongly correlated (r = 0.69–0.83) with frequency of running activities in 50 kindergarten children. The Walk4Life pedometer was later successfully used to detect differences in physical activity between classes that received a physical activity intervention and comparison (control) classes.[60] While neither of these studies actually validated pedometers against other physical activity measures, they nonetheless provided some evidence for the viability of pedometer use with preschoolers.

Three studies were found that have since investigated pedometer validity in preschoolers.[68-70] Louie and Chan[68] used Yamax SW-200 pedometers to measure physical activity in 148 children during 25 minutes of free-play activity in three Hong Kong preschools. The CARS (Children's Activity Rating Scale)[71] was used concurrently to validate the pedometer use, and 30 children were also randomly assigned to wear one pedometer on either hip to provide an indication of pedometer reliability. A significant moderate correlation (r = 0.64) was observed between the total pedometer counts and CARS scores, while no significant difference was found between pedometers worn on either left or right hips.

McKee et al.[69] also validated the Yamax SW-200 using the CARS in 30 children aged 3–4 years. Measurement of self-selected activities was conducted for 1 hour in a nursery-school setting, and results for each 3-minute interval compared. Findings showed moderate-to-strong within-child correlations for the 3-minute intervals of pedometer and direct observation results, ranging from r = 0.64–0.95, with a median of r = 0.86. In a more recent study of 13 preschool children, Oliver et al.[70] assessed the validity of the Yamax SW-200 using the CARS in unstructured free-play sessions of 35 minutes duration. Moderate associations were observed between direct observation and pedometry (r = 0.59, p = 0.04). When the level of agreement[72,73] between the physical activity measures was assessed in the same study, the accuracy of pedometry in assessing free-living activity became questionable.

This contradiction of findings (i.e. a significant moderate association, but low agreement between measures) is an example of the problematic nature of using correlations to establish criterion or convergent validity in physical activity measurement research. Fundamental issues with this approach are

that correlational approaches measure only the strength of a relationship between measurement tools, they are not affected by scale, and any systematic differences between tools is overlooked. Also, the association observed depends on the range and distribution of the true quantity of the variables in the sample.[72,73] Consequently, two measures may have strong and statistically significant correlations, but in actuality the results gathered from the two measures may have low agreement. Using Bland-Altman methods (e.g. limits of agreement, 95% prediction intervals) as applied in the latter study can mitigate these issues.[72,73]

The validity and reliability of pedometers worn at the right hip, left hip and back were also assessed in the Oliver et al.[70] study using observed step counts while walking along a straight line over three pace conditions (slow walk, normal walk, run).[70] Limits of agreement and prediction intervals for directly observed step counts were wide (15–44 steps over 29m) for all pedometer placement sites and pace conditions. In particular, pedometers worn at the back were less accurate than pedometers worn at either hip, and results were more variable for all pedometers during the slow walking condition. The authors proposed that pedometers may be best suited for general assessment of preschoolers' accumulated activity, rather than for research purposes, and that hip placement was preferable to back placement.

Collectively, these six studies provide an indication of the feasibility of using pedometers with preschool children. Correlational studies have shown at least moderate associations for pedometry with direct observation and accelerometry, although this method of data analysis may be inherently flawed for establishing validity. The one study that has used an alternative method of data analysis to reduce issues associated with correlations showed wide limits of agreement and prediction intervals; however, these findings were limited by a small sample size.

1.2 Accelerometers

Accelerometers are lightweight, waterproof motion sensors that record detailed information on movement counts, physical activity intensity and date and time of activities. Modern motion sensors (e.g. ActiGraph, Actical, Caltrac, RT3) use piezoelectricity to register accelerations, whereby crystalline structures are subjected to motion and generate a level of voltage in direct relation to the level of motion/stress. As shown in table I, more than half of the identified studies in preschool physical activity (63%) have utilised accelerometry, with a majority of these (21 studies) having used the Manufacturing Technologies Inc. 7164 ActiGraph (MTI; Shalimar, FL, USA) [previously the Computer Science and Applications {CSA} 7164 Agtigraph]. Five other devices have been used with this population, the Actical and Actiwatch accelerometers (Mini-Mitter Co., Inc. Bend, OR, USA), the Caltrac (Muscle Dynamics Fitness Network, Torrence, CA, USA), the Large Scale Integrated physical activity monitor[74] and the RT3 (Stayhealthy Inc., Monrovia, CA, USA) [previously the TriTrac R3D]. These instruments vary in size, weight and the number of planes (horizontal, vertical, and/or diagonal) that movement is measured in. All accelerometers measure accelerations in the vertical plane, as this has been shown to be most important for measuring ambulatory movement.[74] The RT3 also measures accelerations in the horizontal and diagonal plane creating a 3-dimensional measure of movement, while the newer Actical accelerometers contain piezoelectric transducers that are sensitive to accelerations caused by bodily movement in multiple planes of motion, with one end of the sensor fixed and the other end able to move about freely. This technology means that the Actical is the only commercially available accelerometer that can provide an assessment of omnidirectional activity. Readers are directed to the reviews by de Vries et al.,[75] Rowlands[76] and Sirard and Pate[15] for detailed overviews of accelerometers used with children.

Whether multi-directional accelerometry is best suited for quantifying the characteristically variable activities of young children in free-living conditions

is yet to be established. Research findings comparing single axis accelerometry with multi-axis accelerometry in school-aged children have been unclear.[77,78] Correlational approaches have been the predominant method of analysis in the accelerometry literature to date. As previously discussed in section 1.1, this methodology is problematic in determining accuracy of activity measurement tools.

Table II summarises the 18 studies found that investigated accelerometer validity in preschool populations. Two papers reported Actical accelerometer validity findings using $\dot{V}O_2$ as a criterion assessment.[79,80] Strong associations were observed for the Acticals worn both at the back and hip, and within laboratory and unstructured free-play settings. Direct observation was the only measure utilised to assess the validity of Caltrac accelerometers in preschool children in the five studies found,[16,81-84] issues of which are discussed in section 2.1. Associations were variable both within and between studies (r = 0.25–0.95), and differences were observed between indoor and outdoor play (r = 0.47–0.56 and r = 0.16–0.48, respectively).[84] The weaker associations found for outdoor play might have been due to difficulties in accurately observing children in the outdoor (and possibly less restricted) settings, or because activities that young children participate in whilst outdoors are not as well assessed by the Caltrac as indoor activities.

In contrast, the ActiGraph (also known as the CSA/MTI 7164) has been relatively well researched in six studies using a variety of settings, measurement durations (up to 3 days[89]), and differing criterion measures (direct observation, doubly labelled water, $\dot{V}O_2$). Associations have ranged from r = 0.33 for doubly labelled water[89] to r = 0.75–0.82 for $\dot{V}O_2$[79,85] and r = 0.52–0.87 for direct observation.[86-88,90] The weaker association found for doubly labelled water may be related to the increased duration of physical activity assessment (3 days), compared with a maximum of 1 hour for direct observation.[86] Another explanation may be that these monitors do not associate well with EE determined by the doubly labelled water method. This phenomenon was observed in a validation study of

Actiwatch accelerometers using doubly labelled water as a criterion measure, whereby a weak, non-significant association was found between the Actiwatch and total EE as determined with doubly labelled water.[93] Also, the study protocol involved a measurement period of 7 days, which was substantially longer than other studies that assessed the validity of Actiwatch accelerometers (26 minutes to 6 hours).[90-92] Relationships between physical activity measured using the Actiwatch and by direct observation were highly variable, ranging from r = 0.03–0.92 for data using 1-minute epochs,[90-92] and r = 0.33–0.79 for data using 15-second epochs.[91]

Accelerometers have several limitations. Their high unit cost potentially limits their use for larger research studies, and their units of measurement (counts) have less intuitive utility than pedometer step counts. These motion sensors are also unable to detect increased energy cost from upper-body movement (e.g. digging in a sandpit), load carriage (e.g. pushing a trolley), changes in surfaces or terrain (e.g. walking on soft surfaces) and some types of physical activity (e.g. swimming, cycling). In fact, Bassett Jr. et al.[94] suggested that accelerometers overestimate the cost of walking and underestimate the cost of many other activities when used in free-living conditions.

In addition, there are a number of contentious issues related to how best to analyse accelerometer data, which make comparison across studies difficult.[95] In particular, the identification of appropriate cut-off points for physical activity classifications is yet to be determined for children.[96,97] Until a consensus is reached, detailed descriptive accelerometer data should be reported to enable comparison across studies.

2. Subjective Measures of Physical Activity

Traditionally, physical activity type and patterns in early childhood have been determined by direct observation, a method of observing children and coding physical activity performed. While systematic observation is sometimes considered to be objective (as a result of stringent observer training and

Table II. Validation of accelerometer use in preschoolers

Study	Measurement protocol	Variables	No. of participants (gender, age)	Criterion measure	Validity	Reliability
Actical						
McIver et al.[79]	10 min rest, 5 min walk at 3.2 km/h, 4.8 km/h and jog at 6.4 km/h	Counts/activity stage	16 girls, 14 boys; 3–5y	$\dot{V}O_2$ (portable metabolic analyser)	r = 0.86 for hip; r = 0.87 for back	NA
Actical; 15 sec epochs						
Pfeiffer et al.[80]	3 structured activities in laboratory setting; unstructured indoor and outdoor play; 20 min	Mean counts/min MVPA VPA	11 girls, 7 boys; 4.4 ± 0.7y	$\dot{V}O_2$ (portable metabolic analyser)	r = 0.89 with lab activities; r = 0.59 with unstructured play κ = 0.46 with MVPA κ = 0.71 with VPA	NA
ActiGraph; 15 sec epochs						
McIver et al.[79,85]	10 min rest, 5 min walk at 3.2 km/h, 4.8 km/h and jog at 6.4 km/h; Cross-validation 20 min unstructured indoor and outdoor play	Counts/activity stage	16 girls, 14 boys; 3–5y	$\dot{V}O_2$ (portable metabolic analyser)	r = 0.82 across all activities; cross-validation ICC r = 0.57	NA
Sirard et al.[86]	Study 1: 5 × 3 min structured activities for validity and hip placement reliability Study 2: daycare setting; 1h × 1–3d for validity	Study 1: SED, LPA, MPA and VPA cut-offs based on CARS Study 2: mean counts/15 sec and cut-offs from study 1	Study 1: 5 girls, 11 boys Study 2: 144 girls, 125 boys; 3–5y	DO (modified CARS)	Study 1: sensitivity and specificity for cut-offs were 86.7–100% and 66.7–100%, respectively Study 2: r = 0.46–0.70	r = 0.86 for left and right hips
ActiGraph; 1 min epochs						
Fairweather et al.[87]	Structured activity session; 40–50 min	Mean counts/min	8 girls, 3 boys; 3–4y	DO (CPAF)	r = 0.87	r = 0.98–0.99 with in vitro; r = 0.92 with hip placement, but left vs right hip differed (p < 0.05)
Reilly et al.[88]	Nursery; 40 ± 2 min	SED cut-off of <1100 counts/min	31 girls, 21 boys; 3–4y	DO (CPAF); levels 1–2 considered SED	Sensitivity and specificity for SED was 83% and 82%, respectively	NA

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Table II. Contd

Study	Measurement protocol	Variables	No. of participants (gender, age)	Criterion measure	Validity	Reliability
Montgomery et al.[89]	3d preschool-aged children; 7–10d school-aged children	Total counts	52 girls, 52 boys; 2–7y	PAL$_{DLW}$ (TEE/pREE)	r = 0.33 with total PA	NA
		% time in LPA			r = 0.31 with LPA	
		% time in MVPA			r = 0.22 with MVPA	
		% time in SED			r = –0.33 with SED	
Kelly et al.[90]	Structured play class, 39–45 min	Mean counts/min for total time	48 girls, 30 boys; 3–4y	DO (CPAF)	r = 0.72 for total time	NA
		Mean minute-to-minute counts/min			r = 0.52 for minute-to-minute counts	
Actiwatch; 15 sec and 1 min epochs						
Finn et al.[91]	Gross motor activity class; 26.4 ± 7.8 min	Mean counts/15 sec;	12 girls, 11 boys; 2–5y	DO (CARS)	r = 0.33–0.79 with 15 sec	NA
		Mean counts/min			r = 0.15–0.92 with 1 min	
Actiwatch; 1 min epochs						
Finn and Specker[92]	Childcare setting; 5–6h	Mean counts/3 min	24 girls, 16 boys; 3–4y	DO (CARS)	r = 0.03–0.92 (median 0.74)	NA
Kelly et al.[90]	Structured play class, 39–45 min	Mean counts/min for total time	48 girls, 30 boys; 3–4y	DO (CPAF)	r = 0.16 (NS) for total time	NA
		Mean minute-to-minute counts/min			r = 0.55 for minute-to-minute counts	
Lopez-Alarcon et al.[93]	7d	Total counts/d	12 girls, 17 boys; 4–6y	TEE$_{DLW}$	r = 0.27 (NS)	NA
Caltrac						
Klesges et al.[83]	Caltrac – 1d; DO – unstructured PA at home; 1h; 5d after Caltrac	Not stated	100 girls, 122 boys; 3–6y	DO (SCAN-CAT)	No association found	NA
Mukeshi et al.[84]	Indoor and outdoor play	kcal/h	9 girls, 11 boys; 2–3y	DO (FATS)	r = 0.25–0.62 for total kcal/h; r = 0.47–0.56 for indoor; r = 0.16–0.48 for outdoor	NA
Klesges et al.[82]	Unstructured free-play session in daycare centre; 1h	Total counts/h	12 girls, 18 boys; 2–6y	DO (FATS)	r = 0.39	NA
Klesges and Klesges[81]	Unstructured PA at home and in neighbourhood; 7–11h	Total counts/h	13 girls, 15 boys; 2–4y	DO (FATS)	r = 0.62–0.95 for hourly	NA

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Table II. Contd

Study	Measurement protocol	Variables	No. of participants (gender, age)	Criterion measure	Validity	Reliability
		Total counts/d			r = 0.54 for full day	
Noland et al.[16]	Unstructured free play	Total counts/h	22 girls, 29 boys; 2–5y	DO (CARS)	r = 0.86	NA
LSI						
Klesges et al.[82]	Unstructured free-play session in daycare centre; 1h	Total counts/h	12 girls, 18 boys; 2–6y	DO (FATS)	r = 0.38	NA

Actical = omnidirectional accelerometer; **ActiGraph** = uni-axial accelerometer, previously known as the CSA 7164; **Actiwatch** = bi-axial accelerometer; **Caltrac** = uni-axial accelerometer; **CARS** = Children's Activity Rating Scale; **CAT** = Children's Activity Timesampling method of observation; **CPAF** = Children's Physical Activity Form; **DLW** = doubly labelled water; **DO** = direct observation; **FATS** = Fargo Activity Timesampling Survey; **ICC** = intraclass correlation coefficient; **LPA** = light physical activity; **LSI** = Large Scale Integrated physical activity monitor; **MPA** = moderate physical activity; **MVPA** = moderate-to-vigorous physical activity; **NA** = not applicable; **NS** = not significant; **PA** = physical activity; **PAL** = physical activity level; **pREE** = predicted resting energy expenditure; **SCAN** = Study of Children's Activity and Nutrition; **SED** = sedentary activity; **TEE** = total energy expenditure; **V̇O₂** = oxygen consumption; **VPA** = vigorous physical activity.

ensuring high levels of inter-observer reliability), this method is nonetheless reliant on human observation, interpretation and recording of activity, and thus is inherently subjective.[98] By their nature, surveys and questionnaires are also subjective, as they require individuals to report on their own behaviours, or those of another individual (e.g. parental or teacher reports of child activity). Questionnaires and direct observation methods that have been assessed for their accuracy in measuring preschoolers' physical activity are discussed in sections 2.1 and 2.2.

2.1 Direct Observation

Direct observation is often considered a 'criterion' measure for physical activity in young children due to its practical and comprehensive nature.[15] A search of the literature identified six observation instruments used with preschool-aged children: the CARS,[71] the OSRAC-P (Observational System for Recording Physical Activity in Children-Preschool Version),[99] the SCAN-CAT (Studies of Children's Activity and Nutrition-Children's Activity Time sampling method of observation),[59] the BEACHES (Behaviors of Eating and Activity for Children's Health Evaluation System),[100] the CPAF (Children's Physical Activity Form)[101] and the FATS (Fargo Activity Timesampling Survey).[102]

The CARS has been the direct observation tool most used as a criterion measure for accelerometer (four studies) and pedometer (three studies) validation in preschoolers (see table II and section 1.1), as well as for assessing the activity levels of this population (see table I). The CARS protocol allows for coding of activity in five different categories (resting, low, medium, medium-to-high, vigorous), which may be noted once only within any given minute. This system has been assessed for its practicality and inter-observer reliability over a 12-month period in children (n = 491) aged 3–4 years.[71] No child reactivity was recorded for 93.3% of the observations, and high inter-observer agreement (84.1 ± 10.1%) was found for the 389 paired observation periods with the younger children. The validation (using V̇O₂) of this tool was only conducted with

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older (5–6 years old) children, whereby significant differences in $\dot{V}O_2$ were found for each CARS level. Evidence for the between-day and between-year stability of the CARS in preschool children has been shown by DuRant et al.,[103] with a reliability coefficient of r = 0.57 for 5.4 days of observation over a 3-year period. Higher levels of reliability were found for the percentage of minutes spent at higher CARS levels (r = 0.75 for levels 3–5; r = 0.74 for levels 4–5), indicating that high-intensity activity may be more stable in this population than sedentary and/or low-intensity activity.

A modified version of the CARS, the OSRAC-P[99] was developed with preschool children to allow researchers to capture more detailed contextual information including activity type, location and social environment. Due to the greater information requirements, a short observation of 5 seconds is followed by a longer recording time of 25 seconds. The OSRAC-P was tested in three preschools, and kappa (κ) and category-by-category inter-observer agreement values of >0.80 were found for all categories except group composition (κ = 0.79), although wide ranges were found for both physical activity level and type (κ = 0.18–1.00 and 0.50–1.00, respectively). Such variation in observer agreement shows the vulnerability of direct observation methods, with its reliance on accurate researcher observation, interpretation and recording. No validation of this measure in preschoolers has been conducted. An adapted version of the OSRAC-P, the OSRAP (15 seconds observation, 15 seconds recording) has been successfully used in two studies of preschool children to measure physical activity;[5,57] however, no reliability nor validity testing of this instrument has been reported with young children.

The SCAN-CAT has been used in one study to assess physical activity levels in preschool children.[59,83] The SCAN-CAT protocol entails 10 seconds of observation followed by 10 seconds of recording. As well as physical activity level, information on the physical and social environment is also recorded. No studies were found that reported validity or reliability of this measure in preschool children. In contrast, the BEACHES was widely reported due to its application in the SCAN study,[46-50] as is indicated in table I. Stability and inter-observer agreement has been assessed for the BEACHES in 42 children aged 4–8 years.[100] Stable estimates for the measure were achieved with four, 60-minute observation sessions in the child's home. Nineteen observation sessions were evaluated for inter-observer reliability, with agreement ranging from 94% to 99% (median κ = 0.71–1.0). This finding was likely due to stringent protocols applied by the researchers, including fortnightly training and review sessions, and frequent reassessment of observer accuracy. The BEACHES was also evaluated for validity in a separate sample of 19 children aged 4–9 years, using heart rate telemetry as a criterion measurement. Findings showed that heart rate (and calculated EE) increased concurrently with each increase in the five BEACHES activity categories (lying – very active); however, the relationship between the BEACHES and heart rate was not calculated. Furthermore, the use of heart rate in quantifying activity in young children is limited, and heart rate is considered an indicator of EE rather than physical movement (see section 3). Further work is needed to determine the validity of this instrument using more specific comparison measures.

Heart rate monitoring has also been used to validate the CPAF in children aged 8–10 years.[101] The CPAF involves activity coding in four different categories (stationary – no movement, stationary – limb movement, slow trunk movement, rapid trunk movement), that can be noted only once within each minute. In the validation study with school-aged children, progressive increases in CPAF activity level were reflected with increased mean heart rate for 7 of 9 activity point categories. A mean correlation of r = 0.641 between heart rate and the CPAF was found for all participants (range r = 0.26–0.90), and time series regression analysis revealed that 72% of the variation in heart rate could be accounted for by the CPAF. Average inter-observer reliability for 57 paired observations over 3 years ranged from 96% to 98%.

The FATS[102] is the only direct observation method that has been validated using an objective measure of physical activity in preschoolers. Correlations of r = 0.78–0.90 with the Large Scale Integrated physical activity monitor were found in the sample of children (n = 14) aged 2–4 years. The use of an activity monitor as opposed to indicators of EE as a criterion measure is a novel approach worthy of further investigation when validating observational methods in preschoolers. Interestingly, while not validated for use with children aged <5 years, the SCAN-CAT,[83] CARS[16,86,91,92] and CPAF[87,88,90] have all been used as 'criterion' measures for the validation of accelerometers in preschool-aged children. This use of direct observation tools that have not been validated in the research population of interest as 'criterion' measures raises concerns regarding the accuracy of these study findings. At the same time, these studies could be considered as providing evidence for the convergent validity of these direct observation tools, using accelerometers that in most instances have been widely evaluated and validated with young children.

Strengths of direct observation include the ability to gather detailed information on children's activity patterns and types in a variety of settings, including the ability to measure upper-body movement. The BEACHES and OSRAC-P in particular allow for the measurement of detailed related information such as the environment, location and individuals interacting with the child at the time of observation. Direct observation methods do not rely on parents' or teachers' ability to accurately recall physical activities of children being studied. Although hand-held devices may be used for recording data in real-time, these are not essential, and no other equipment is necessary for data collection. Lastly, direct observation methodologies are relatively unobtrusive to the child under study. Conversely, direct observation has a number of limitations. As noted earlier, this method is inherently subjective. Children may change their behaviour due to the research procedure. The processes of observer training and data collection are time consuming and thus expensive, and so direct observation is not feasible for large-

scale studies, or for individual data collection over extended periods of time. Also, coding protocols do not allow for continuous recording of activity, which may result in an inability to adequately assess intermittent activities.

2.2 Questionnaires/Diaries

Eight studies were found that assessed the validity and/or reliability of physical activity questionnaires or diaries with preschool-aged children, all of which are outlined in table III. In all of these studies, questionnaires or diaries were completed by proxy report, either by the parent or teacher of the child. One study compared accelerometer-determined activity with physical activity derived from a time activity diary for nine children aged 4–17 months.[104] Predominant activity (sleeping, eating, quiet playing, active playing) and location (home-inside, home-outside, away from home) were coded by the child's primary caregiver every 30 minutes for ≤ 4 days, concurrent with accelerometer wear. A moderate association (r = 0.42) and low-to-moderate concordance (57–78%) was found between accelerometer and diary measures. High variability of accelerometer counts for the diary activity classifications both between and within individuals likely reduced the strength of these relationships. Interestingly, although this method involved comparatively high participant burden, 100% compliance was achieved. Three studies used questionnaires that required the proxy reporter to recall specific activity from the previous 3[105,106] to 4 days,[107] during which time accelerometer-determined physical activity was also measured. Chen et al.[105] found that children whose physical activity frequency was rated as 'not often' on their 3-day questionnaire had significantly lower accelerometer counts compared with children who were rated as 'very often' active. Moderate associations of r = 0.33 for total activity and r = 0.53 for moderate-to-vigorous physical activity were found for the 3-day checklist of Burdette et al.[106] and the 4-day questionnaire of Harro,[107] respectively. The stronger correlation found in the latter study may be due to the investigation of a specific physical activity variable (percentage of

Table III. Validation of proxy-report questionnaires and diaries to assess preschoolers' physical activity

Study	Questionnaire	Proxy reporter	No. of participants (gender, age)	Criterion measure	Validity	Reliability
Burdette et al.[106]	Checklist for outdoor play time for the measurement period (3d) Recall of usual outdoor playtime in previous month (min/d)	Parent	107 girls, 143 boys; 2–4y	Tritrac-R3D; 3d	r = 0.33 for checklist r = 0.20 for recall	NA
Goran et al.[108]	Modifiable activity questionnaire (h/d of PA, sleep, TV watching)	Mother	53 girls, 48 boys; 5.3 ± 0.9y	AEE_DLW; 14d	No significant correlation observed	NA
Klesges et al.[83]	Energy Balance Questionnaire of the SCAN	Parent	100 girls, 122 boys; 3–6y	DO; Caltrac	Maternal reported questions loaded moderately (0.54–0.71) on to a 'general activity' factor	NA
Saris and Binkhorst[109]	Netherlands Physical Activity Questionnaire for Young Children (usual PA patterns and preferences)	Parent/teacher	11 children; 4–6y	Pedometer	Questionnaire PA categories distinguished between different pedometer PA categories	NA
Janz et al.[110]	Netherlands Physical Activity Questionnaire for Young Children (usual PA patterns and preferences)	Parent	113 girls, 91 boys; 4–7y	ActiGraph; 4d	r = 0.33 with total PA; r = 0.36 with VPA	Intraclass reliability correlation coefficient r = 0.70
Telama et al.[111]	Questions on average outdoor play, perceived levels of play, child's preferred activities	Parent	278 girls, 294 boys; 3y	NA	Internal consistency coefficients: r = 0.63 for girls; r = 0.60 for boys	NA
Chen et al.[105]	Questions on children's PA levels during measurement period	Nursery teacher	9 girls, 12 boys; 3–4y	Actiwatch; EE (Caloriecounter Select II); 3d	Questionnaire PA categories distinguished between different accelerometer PA categories and Caloriecounter EE categories	NA
Harro[107]	Questions on children's PA levels, active transportation and sedentary behaviours during the measurement period	Parent and teacher	32 girls, 30 boys; 4–8y	Caltrac; HR; 4d	% time MVPA from questionnaire r = 0.53 with Caltrac; r = 0.40 with HR	NA
Tulve et al.[104]	Time activity diary for every 30 min over 4d, including PA level and location	Parent	4 girls, 5 boys; 4–17mo	Actical; 4d	r = 0.42 for total PA; 70% concordance between accelerometer count and diary PA level tertiles	NA

ActiGraph = uni-axial accelerometer, previously known as the CSA 7164; **Actiwatch** = uni-axial accelerometer; **AEE** = activity energy expenditure; **Caltrac** = uni-axial accelerometer; **DLW** = doubly labelled water; **DO** = direct observation; **EE** = energy expenditure; **HR** = heart rate 'elemetry; **MVPA** = moderate-to-vigorous physical activity; **NA** = not applicable; **PA** = physical activity; **SCAN** = Study of Children's Activity and Nutrition; **Tritrac-R3D** = tri-axial accelerometer; **TV** = television; **VPA** = vigorous physical activity.

time in moderate-to-vigorous physical activity) as opposed to total daily activity, or as a result of gathering information from both parents and teachers. The Harro[107] study was the only one to take such an approach, which may be worthy of further investigation as it allows the researcher to gather information on total daily physical activity at home, and within early childhood education and care settings.

Burdette et al.[106] also assessed the validity of parental recall of usual outdoor playtime in the previous month with 3-day tri-axial accelerometry. A weaker correlation was observed for the usual activity recall than the 3-day checklist discussed earlier (r = 0.20 vs 0.33). This indicates that either the usual activity recall questionnaire was not sufficiently accurate, or that the 3-day accelerometry assessment may not be a valid indicator of usual activity. Indeed, a monitoring period of 6 days using ActiGraph accelerometers has been shown as necessary to provide an accurate representation of the usual physical activity of young children within a preschool setting.[112] Four other studies also assessed questionnaires that measured 'usual' or 'normal' activity as opposed to actual activity over a given timeframe.[108-111] The NPAQ (Netherlands Physical Activity Questionnaire) of usual physical activity patterns has been investigated in two preschool studies using pedometry[109] and accelerometry.[110] Saris and Binkhorst[109] found that the NPAQ could distinguish between children in differing activity categories assessed by pedometry, while Janz et al.[110] found moderate correlations between the NPAQ and accelerometer-determined total physical activity (r = 0.33) and vigorous activity (r = 0.36). Although an accepted criterion measure was not used in the study by Saris and Binkhorst[109] the study is worthy of consideration as it provided supporting evidence for the utility of this questionnaire. Telama et al.[111] assessed the internal consistency of a questionnaire on children's average amount of outdoor play, and parental perceptions of their child's activity levels and activity preferences with promising findings (r = 0.60–0.63). The questionnaire is yet to be validated against a comparison measure. One study used EE as assessed with the doubly labelled water method to validate a questionnaire on young children's hours per day of activity, sleep and television watching. No significant relationships were found between the measures.[108] It is possible the questionnaire used in this study did not adequately assess children's physical activity, but it is also important to consider that EE may not be an appropriate 'criterion' measure for tools that attempt to assess physical activity level and patterns in this population. Another explanation for this finding is that the questionnaire did not assess physical activity for the same timeframe as the criterion. For example, the studies of Harro[107] and Chen et al.[105] showed evidence for the validity of activity questionnaires using indicators of EE (heart rate telemetry and the Caloriecounter), when the questionnaire assessed activity for the same period as the criterion assessment. This lack of significant and/or strong relationships between EE and physical activity measurement tools has also been observed with accelerometers, as discussed earlier in section 1.2.

No standardised questionnaire has been developed and sufficiently evaluated for the assessment of physical activity in preschool-aged children. Further confounding this problem is a general inability of young children to accurately self-report on duration, frequency and/or intensity of physical activities performed,[113] and so self-report methodology should not be applied with children aged <10 years.[114] Strengths of questionnaires are that they are inexpensive, are not invasive, and can be less time consuming to administer and interpret than objective alternatives of activity assessment. Although more time consuming than questionnaires, detailed information on activity intensity and context can be gained with proxy-report time activity diaries. Further investigation is required to determine the validity of these tools for use with preschool-aged children.

3. Energy Expenditure

EE is the amount of energy used at rest (REE), during activity (AEE) and over a total period of time (TEE). EE has been considered a separate variable

to physical activity in the current review, as physical activity is only one factor that contributes to EE. For example, a study of children aged 5 years showed that physical activity accounted for only $16 \pm 7\%$ of TEE for the 7 days monitored.[115] One explanation may have been that the participants exhibited extremely low physical activity levels over the measurement period; however, it is likely there were also other influencing factors. For example, genotype can influence approximately 40% of the variance in REE and low-to-moderate physical activity.[116] In a study of Caucasian and African-American children, the Caucasian children exhibited significantly higher REE, even after adjusting for age, pubertal maturation and body composition.[117] Conversely, in a study of children from four ethnic groups, ethnicity did not influence REE, but did affect TEE and AEE, boys had a higher REE than girls, and bodyweight was the best predictor of TEE.[118] Likewise, a large study of obese and non-obese children showed that while physical activity was higher in the non-obese children, EE of the obese children was higher than that of the non-obese children.[119] A comparison of heart rate response to exercise in obese and non-obese children found that heart rate was significantly higher in children with increased skinfold thicknesses both during and after exercise.[120] Although more time consuming than questionnaires, detailed information on activity intensity and context can be gained with proxy-report time activity diaries. Further investigation is required to determine the validity of these tools for use with preschool-aged children.

Given that overweight and obesity are often variables of interest when assessing physical activity and health outcomes, this confounding effect of weight status can mean that EE will not accurately depict the relationship between activity and body size, and the true effect of physical activity is likely to be masked. A 4-year longitudinal study of children's body size and REE, AEE and TEE showed that body size was not related to EE, but instead was related to sex, initial fatness and parental fatness.[121] One study concluded that AEE should be normalised for fat-free mass to control for the confounding influences of gender, age and body size on EE calculations.[122] Another study found that, after adjusting for initial body composition, age, ethnicity, gender and maturational stage, REE, AEE and TEE did not predict increasing adiposity in children; however, aerobic fitness did.[123] In summary, EE is a complex variable determined by a multitude of factors, and so should not be considered an exact account of physical activity. It is worth noting that despite this limitation, EE is routinely utilised as a 'criterion' measure for assessing physical activity measurement tools (see table II). Moreover, EE has been used to validate direct observation (see section 2.1), which in turn has been used as a 'criterion' measure for motion sensors (see section 1.1 and table II).

Heart rate monitoring is especially limited as a physical activity proxy or 'criterion' as it is an indirect approximation of EE that is reliant on the assumption that a linear relationship exists between heart rate and $\dot{V}O_2$. Heart rate is sensitive to a number of factors including emotional stress, body position and digestion.[124,125] At lower levels of activity, these factors may confound the relationship between heart rate and $\dot{V}O_2$ and thus provide an inaccurate estimation of physical activity level.[124,125] Furthermore, the variety of methods employed to define resting heart rate in children can lead to substantial differences in activity classification when heart rate is extrapolated to physical activity level.[126]

4. Issues with Physical Activity Assessment in Preschoolers

Further to validity and reliability assessment of potential measurement tools, consideration must be given to the ability of these tools to capture the movement types and patterns unique to preschool children. Particular facets of activity participation in young children that are important to consider are outlined in sections 4.1–4.3.

4.1 How Do Preschool Children Move?

The choice of appropriate physical activity measurement tools will be influenced by the develop-

mental stages of preschool-aged children and subsequent physical activity types and patterns that are typical of this population. The social and physical development that occurs during early childhood means that compared with school-aged children, preschoolers participate in activities that require less vertical movement (e.g. ambulation during organised activities) and more omnidirectional movement (e.g. rolling and climbing in solitary and pretend play).[127,128] Accordingly, if motion sensors are being used, monitors that are capable of capturing measurement over more than one plane of movement are recommended. Additionally, movement (especially walking) patterns of young children may have more horizontal motion than that exhibited by older children, due to their wider base of support during gait development.[129] As such, motion sensor readings may be dependent on location of the sensor (e.g. hip or back placement).

4.2 Physical Activity Patterns in Preschoolers

Table I shows the studies found that have assessed physical activity in preschool-aged children. Due to the range of data collection methodologies used across a small number of studies (with small sample sizes), it is not possible to identify clearly the physical activity characteristics of this population, nor to compare findings across studies. Even so, some interesting patterns in physical activity can still be found from the literature. For example, there is a general consensus that young boys are more active than young girls. The ability to gather contextual information concurrent with physical activity quantification to explain this gender difference would, therefore, be useful. It also appears that preschool-aged children participate in very little vigorous physical activity and exhibit high levels of sedentary behaviour. When children are active, movement is characterised by short bursts of activity, and velocity and movement types can vary considerably.[130-133] These findings highlight the importance of being able to quantify and categorise physical activity intensities and sedentary behaviours in young children. Frequent time-sampling (e.g. epochs of 10–15 seconds) with any measure

may be especially important, to be able to discern between physical activity intensities.

4.3 Preschoolers and Sedentary Pursuits

Physical inactivity (or sedentary activity) is a construct related yet distinct from physical activity, and is related to health-risk behaviours such as increased consumption of unhealthy foods.[134,135] Inactivity is commonly assessed in terms of screen time exposure (e.g. television/movie watching, computer use, game console use).[14,136] Two studies have reported the application of an objective measure of television watching, the TV Allowance™ (Mindmaster Inc., Miami, FL, USA) monitor.[33,137] Robinson et al.[137] successfully used this device to assess television watching time over 3 weeks with 80 children at risk of overweight/obesity aged 4–7 years. Findings showed that children with a television in their bedroom watched significantly more television than children without a bedroom television (29.8 ± 14.2 and 21.4 ± 9.1 hours/week, respectively). Interestingly, parental reports of the amount of child television viewing were significantly overestimated when no television was in the child's room, and significantly underestimated when the child had a television in their bedroom. Similar levels of objectively assessed television watching time for young boys and girls were reported by Roemmich et al.[33] (24.3 ± 9.1 and 23.7 ± 9.0 hours/week, respectively). Reilly et al.[88] have also recently established accelerometer cut-off points to enable objective quantification of sedentary behaviour in preschoolers. The amount of sedentary behaviour may be more important to assess than physical activity levels when investigating relationships between physical activity and health in preschool-aged children. For example, >2–3 hours daily of inactivity has been associated with increased overweight and obesity in cross-sectional and longitudinal studies of preschool-aged children.[12-14,27,138-140] Furthermore, high amounts of television viewing (>2 hours daily) has been observed in infants, and this indicator of inactivity has been shown to track into childhood.[141] The relationship of inactivity to health outcomes highlights the importance of using

tools that are capable of identifying sedentary behaviour patterns in this population, as an overall measure of total activity may not appropriately describe the physical activity behaviours that could be related to health.

5. Future Research

Further investigation of all the motion sensors previously described is required to examine their accuracy and utility in differing settings (e.g. indoors vs outdoors) and over different periods of time. More work also needs to be done to determine how best to identify cut-off points for physical activity intensities in young children. The accuracy of pedometers with preschoolers is still yet to be clearly established. The Yamax SW-200 is the only pedometer that has been assessed for validity with preschool-aged children. The utility of alternative pedometer models for use with preschoolers is yet to be determined.

The NL2000 pedometer can collect daily physical activity data over a maximum of 7 days, and is more accurate than the Yamax DW series in school-aged children walking at slow speeds.[142] Both the Yamax DW/SW series and NL2000 pedometers are unable to capture activity intensities, which may be of particular importance when considering preschool activity and health. The ankle-mounted StepWatch Activity Monitor[143] is the only pedometer that can quantify activity patterns and intensities, collecting data in epochs from 6 seconds to 25.5 minutes, but is yet to be evaluated with preschoolers.

Reactivity to motion sensor use with preschool children is not well understood. It is possible that potential reactivity may be mitigated by pedometer placement at the back of the child, or by increased pedometer exposure; however, these approaches are not well understood. More research is required to understand the effects of age, body size (particularly abdominal adiposity) and velocity differences on pedometer accuracy.

A number of accelerometers have been used with older populations, including: the MINI-LOGGER (Mini Mitter, Sunriver, OR, USA), the ActivPAL (PAL Technologies Ltd., Glasgow, UK), the Actillume actigraph (Ambulatory Monitoring, Inc., Ardsely, NY, USA), the Biotrainer (IM systems, Balitmore, MD, USA), the Kenz accelerometer (Select 2 Model, Nagoya, Japan) and the Tracmor (Philips Research, Eindhoven, the Netherlands).[74] Whether these accelerometers are reliable and valid for use with children aged <5 years is yet to be determined. An updated version of the ActiGraph, the ActiGraph GT1M, has not yet been assessed with preschool children. The ActiGraph GT1M uses a digital, solid-state accelerometer rather than the piezoelectric bimorph beam used in the older ActiGraph. Research with adolescent children showed that the ActiGraph GT1M measured approximately 7% higher activity than the original ActiGraph model.[144] It was not clear from the study findings whether the GT1M was more accurate than the older ActiGraph, or whether activity was overestimated using the GT1M. The Actical monitors appear promising for use with preschool children; however, further work needs to be done to assess validity in more free-living situations, over extended periods of time (i.e. >20 minutes), and using alternative criterion measures to $\dot{V}O_2$. It would be worthwhile to consider the convergent validity of the Caltrac in indoor and outdoor settings, using an objective comparison measure (e.g. the Actical or ActiGraph accelerometers).

Irrespective of their limitations, questionnaires and surveys are likely to be employed for large epidemiological studies, as they are inexpensive and easy to administer. Where possible, such data should be substantiated using a valid and objective measure of physical activity in a sub-sample of the population under study. No questionnaire has yet been developed and rigorously assessed for accuracy in measuring the physical activity levels of preschool children. The real utility of questionnaires may be to establish correlates of activity, and to understand contextual and other factors that may inform physical activity interventions.

Although direct observation has been commonly employed in physical activity measurement studies in preschoolers, validation of this methodology with

Table IV. Potential measurement tools to assess preschoolers' physical activity

Tool (manufacturer)	Description	Strengths	Limitations	Reference
Intelligent Device for Energy Expenditure and Activity (IDEAA) (MiniSun, Fresno, CA, USA)	Small hip mounted microprocessor (200g) with five sensors (16 × 4 × 4mm) that attach at the chest, feet, and mid-quadriceps. Output signals are transmitted from the sensors to the microprocessor to provide information on activity type (currently calibrated for 32 activities), gait analysis, and duration, frequency and intensity of activity	Accurate in adolescents and adults; objective; 48h data collection; very detailed data collection; have potential for validation studies as a convergence measure	Wires are obtrusive; not calibrated for activities typical of preschoolers; unlikely to be practical or cost effective for larger studies	145
Partial Pulse Positioning (P³) [Paric Measurement, Auckland, New Zealand]	Position tracking system within a defined space of up to 1000m². A tag worn by individuals transmits signals to four or more fixed receivers surrounding the defined space, and a central controller calculates tag positioning	Accurate to within 1cm; objective; operates accurately indoors (unlike GPS); real-time data output	Captures information in defined spaces only; initial setup is expensive (requires a central control unit, receivers, software); does not assess static activities that include upper-body movement	146
Uptimer (Gorman ProMed Pty Ltd, Melbourne, VIC, Australia)	Leg-mounted lightweight battery-operated unit that measures time spent in upright position (uptime) by activation of one or more mercury tilt switches that are sensitive to the position of the thigh relative to gravity. Data are downloaded to a master unit to determine amount of time in uptime and downtime	Accurate in adults; objective; simple output that can be easily translated to health promotion messages	Not waterproof; does not assess seated activities that include upper-body movement; no indication of activity intensity	147
Global Positioning System-Personal Acquisition Logger (GPS-PAL) [Enertech Consultants, Campbel, CA, USA]	Lightweight GPS monitor (280g) designed specifically for use with children. Comprises a central electronic unit and battery pack integrated into clothing, and an antenna worn at the shoulder. GPS technology involves establishing time and location coordinates from three or more satellite signals, and can be used to track movement of an individual	Accurate in adults and children; objective; frequent time sampling (5 sec epochs) for 25–30h; time and location data enable the quantification of movement velocity	Expensive ($US1000 per unit; 2003 value); signal interference occurs within concrete/steel frame buildings; accurate to within 2–3m outdoors and 4–5m indoors, so not ideal for use in contained environments; Does not assess seated activities that include upper-body movement	148
Infra-Red Beam Counters (IRBCs) [e.g. ONSPOT PC2000]	Transmit an infra-red beam across a designated area. Dual infra-red beam counters register 'counts' when the beam from both the transmitting and receiving units are broken	Objective; unobtrusive; battery life is approximately 3mo	Not accurate in estimating the number of people in park settings; does not provide a measure of physical activity, rather movement across a defined space	149

GPS = global positioning system.

young children is limited. Given that direct observation is purported to be an ideal 'criterion' for physical activity validation studies with preschoolers, this is unquestionably an area for further investigation and clarification. The use of EE as a 'criterion' measure of physical activity is also problematic. As no alternative exists, differing approaches to assessing convergent validity, such as using more than one comparison measure, should be considered for their efficacy. If EE is used as a proxy for physical activity, ideally maximal oxygen consumption ($\dot{V}O_{2max}$) should be used, as this has been shown to be the strongest marker of AEE in preschool children.[118] Heart rate telemetry should not be used either as a 'criterion' measure of physical activity, nor as a proxy for physical activity measurement. Instead, accelerometry could be used as a comparison measure for assessing convergent validity of other motion sensors and of subjective measures of physical activity, or it could also be used concurrently with EE methodologies to better understand the validity of physical activity measurement approaches. Alternatively, direct observation methods using frequent time-sampling (i.e. 10- to 15-second epochs) could be used simultaneously with accelerometry to provide further evidence for convergent validity, and to gather important contextual information.

To date, measures of association have predominantly been employed to assess the validity of physical activity measurement tools in preschoolers. It may be useful in future studies to consider instead the strength of agreement between measures, thereby identifying any potential bias that may exist with particular measures.[73] The ideal approach for assessing the utility of activity measurement tools in preschoolers is thus proposed as a combination of accelerometry and either direct observation (with frequent sampling) or EE, and using measures of agreement (rather than association) when considering the data.

Many other methods of measuring human physical activity have been developed and are yet to be assessed with preschool-aged children. The strengths and weaknesses of some potential measures for use with young children are outlined in table IV. A detailed critique of these measures is beyond the scope of this article, but rather, the inclusion of this table is to provide the reader with a broad understanding of the various tools available for assessment of movement in young children.

6. Conclusions

Physical activity participation may play an integral role in the health of young children. Preceding understanding the relationships between physical activity and health outcomes, it is necessary to establish valid and reliable methods of physical activity quantification in this population. No consensus yet exists on what the preferred method for physical activity measurement in preschoolers is, nor is there a best practice approach for data analysis and consideration of differing units across studies. Considerably more research is required in this field.

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Appendix I: Pedometer accuracy in physical activity assessment of preschool children

ELSEVIER

ORIGINAL PAPER

Pedometer accuracy in physical activity assessment of preschool children

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Summary   Yamax SW-200 pedometer validity during unstructured free play was assessed in 13 preschool children aged 4.1 ± 0.6 years using the Children's Activity Rating Scale (CARS). Pedometer validity and hip placement reliability were also assessed during straight line walking. Data were analysed using regression analyses, 95% upper and lower prediction intervals and 95% limits of agreement. The prediction intervals for pedometry were wide when using the CARS as a criterion. Limits of agreement and prediction intervals for directly observed step counts were also wide for pedometers, calling into question their acceptability for use with preschoolers. Limitations of employing the CARS direct observation approach as a criterion measure of physical activity are also discussed.
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Introduction

Accurate quantification of physical activity in early childhood is recognised as being fundamentally important for a number of reasons including measuring physical activity levels and changes to these levels, establishing dose—response relationships between physical activity and health outcomes, allowing effectiveness of interventions to be ascertained, and to identify children at increased health risk because of their physical inactivity. While considered the "gold-standard" for physical activity measurement,[1] direct observation can be impractical for epidemiological research as it is time consuming, expensive and is reliant on observer precision and presence which is often unfeasible. In contrast, accelerometry and pedometry allow for objective and more efficient data collection. While these motion sensors have been used widely in school-aged children to understand total daily physical activity, limited work has assessed the efficacy of these instruments in younger, preschool-aged children (<5 years).

Accelerometry is the most commonly used objective approach to monitoring free-living physical activity in young children, and a variety of

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accelerometer models have been well validated in this population.[2–11] Accelerometers are not, however, without limitations. Their cost potentially limits their use for larger research studies, and their units of measurement (counts) have less intuitive utility than pedometer step counts or accumulated time spent being active. Consequently, pedometers are often promoted as a preferred alternative to accelerometers for the objective measurement of physical activity, particularly in youth[12] because of their affordability, reliability and validity in assessing free-living physical activity.

The validity and reliability of Yamax Digiwalker SW-200 pedometers (Yamax Inc., Tokyo, Japan) have been demonstrated within a preschool population by Louie and Chan[13] and McKee et al.[14] In both studies, the CARS was used concurrently to validate the pedometers during preschool free-play sessions, with significant correlations found between total pedometer counts and CARS scores ($r = 0.637–0.950$, $p < 0.01$). Louie and Chan[13] also found no significant difference ($p > 0.05$) between pedometers worn on the left and right hips. There remain, however, a number of unanswered questions regarding pedometer use in early childhood populations. For example, no research has investigated pedometer validity in preschoolers using actual step counts as a criterion measure. Placement of pedometers at the back of the child (where it is not in their direct view) may mitigate any reactivity to pedometer wearing, however, the reliability of pedometers worn at the back has not been established in young children.

The current study was developed to gather more empirical evidence for the accuracy of pedometers use with preschool children and to answer some of the outstanding questions. Specifically, the validity of the Yamax SW-200 Digiwalker pedometer measures compared to direct observation values (using CARS) in free play was assessed. Further, the accuracy and reliability of pedometer readings compared with observed steps across three sites of placement (left hip, right hip and back) and over three pace conditions (slow walk, normal walk and run) in these preschool children were investigated.

Methods

Participants

A convenience sample of thirteen 3–5-year-old children attending the Auckland University of Technology Akoranga Crèche (childcare centre for children aged 0–5 years) was recruited for this study. The sample size required for this study was based on the report that a sample of 8–10 children was adequate to detect significant differences between motion sensor readings,[7] and allowed for 25% attrition. The sole exclusion criterion was an inability to walk. Parental consent and participant assent were gained for all stages of the study. Ethical approval to conduct the study was granted by the Auckland University of Technology Ethics Committee (AUTEC). AUTEC guidelines were adhered to at all stages of the study.

Data collection procedures

Two approaches were taken to assess the utility of pedometers to accurately quantify physical activity in preschool children: validity in unstructured free play, and validity and reliability in straight line walking, as detailed below.

1. Validity in unstructured free play. Participants were observed during unstructured indoor and outdoor free-play sessions of 35 min duration in the Crèche, while also wearing a sealed Yamax SW-200 Digiwalker pedometer. The pedometer was attached at the hip (at the anterior superior iliac spine) using a purpose-made elastic waistband. Hip placement (left or right) was randomly assigned. The pedometer was placed on the child and set to ''0'' immediately prior to observation. Upon observation completion and prior to removing the pedometer and belt, the child was asked to stand still while the pedometer reading was recorded.

   The CARS[15] was used to record the observed activity of the children. This measure has been validated using indirect calorimetry, is the most commonly used tool for direct observation, and is also considered a criterion measure in the validation of alternative physical activity assessment tools.[1] The principal investigator and two research assistants completed 10 h of training on CARS administration over a 2-week period. Training involved using the CARS to document physical activity patterns of preschoolers at a variety of activity levels, followed by group discussions to clarify appropriate coding methodology and related issues. Both actual observation of unstructured free-play sessions in early childhood environments, and videotapes of young children participating in a variety of physical activities, were used for training purposes. The CARS method entailed one or more researchers observing a child and recording 1–5 levels of physical activity for each minute of observation. CARS activity levels were categorized on a Likert scale ranging from 1 (resting) to 5 (strenuous,

very high). Any given activity level was coded only once within the minute in which the activity was completed. Minute-by-minute average activity levels were then calculated, and were summed for the entire observation period.

2. Validity and reliability in straight line walking. Participants were requested to ambulate along a straight 29 m line at three different speeds (''walk slowly like a snail'', ''walk normally'' and ''run''), while the principal researcher counted actual steps and measured the time taken with a stopwatch. One trial at each gait speed (slow walk, normal walk and run) was completed in a random order. Participants also wore three sealed Yamax SW-200 Digiwalker pedometers secured to an elastic waistband with safety pins at the left hip, right hip and centre of back. Pedometers were reset to '0' immediately prior to any steps being taken, and accumulated step counts were recorded immediately after ambulation ceased.

Statistical analyses

All calculations were undertaken using SPSS or Stata and statistical significance was set at $\alpha = 0.05$. Due to the small sample size, medians and ranges were used to describe the location and spread estimates.

1. Validity in unstructured free play. Total pedometer steps for the observation period were compared with the sum of the minute-by-minute CARS scores. Pedometer steps were regressed against the criterion measure (physical activity level assessed by the CARS direct observation method) and 95% upper and lower prediction intervals determined.[16] Residual analysis included the plotting of the Studentized residuals against actual pedometer steps with a lowess curve superimposed.[17] This allows patterns in the residuals that would violate the regression assumptions to be detected. The Studentized residuals were subjected to Shapiro—Wilk's test of normality.[17] To enable comparison with previous research,[13,14] the relationship between physical activity scores derived from direct observation and pedometry were also assessed using Spearman's correlation coefficients.

2. Validity and reliability in straight line walking. Agreement between observed steps and step counts from pedometers worn at each location (left hip, right hip or back) was assessed using the Bland—Altman method.[16,18] Initially, Bland—Altman plots and associated lowess curves were produced and assessed for each of the three pedometer placement sites

against the observed steps at each gait speed to determine whether a combined or subgrouped analysis was needed. Assuming negligible correlation between repeated measures, equality in variance between pedometer placement readings for each gait speed (slow walk, normal walk and running) was formally determined using Bartlett's test.[19] Regression analyses were conducted (clustered for repeated measures) to examine the variance in mean difference values between observed steps and each of the pedometer placement readings for each gait speed category. The corresponding 95% limits of agreement were calculated using Student's t critical values.[17] The diagnostics of the analyses were checked to determine whether there was any important violation of assumptions.

Results

Thirteen children (7 boys and 6 girls) aged 3.0—4.8 years (median 4.2) participated in the study.

1. Validity in unstructured free play. Fig. 1 shows the linear prediction and 95% prediction intervals for the pedometer data against CARS physical activity levels for the 35 min free-play session. As can be seen in Fig. 1, the 95% prediction interval associated with the pedometer data is wide. For example, at a pedometer count of 1000 steps, the 95% prediction interval ranges from a CARS activity level of 60.3 to 104.8 (width 44.5). This could also be interpreted as follows. At 1000 pedometer steps, the 95% prediction interval ranges from an average CARS activity level of 1.7 min^{-1} (resting) to 3.0 min^{-1} (medium to moderate activity), for
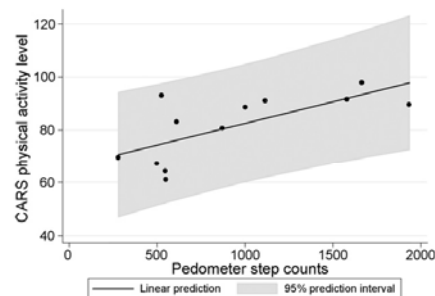

Figure 1 Linear regression and 95% upper and lower prediction intervals of pedometer step counts in predicting CARS physical activity level for 35 min of unstructured free play.

Table 1 Median and range (minimum and maximum) of the steps observed and recorded from pedometers placed on the left, right and back and partitioned by gait speed

Gait speed	Observed		Left		Right		Back	
	Median	Minimum, maximum	Median	Minimum, maximum	Median	Minimum, maximum	Median	Minimum, maximum
Normal	60	40, 80	62	50, 76	61	49, 85	63	56, 91
Running	44	42, 63	48	38, 66	48	41, 66	49	41, 66
Slow walk	70	56, 81	68	54, 73	70	48, 80	70	53, 81
Combined	60	40, 81	62	38, 76	60	41, 85	63	41, 91

the 35 min period. Residual analyses provided no evidence for the violation of assumptions. A significant moderate correlation was observed between direct observation and pedometry ($r = 0.59$, $p = 0.04$).

2. Validity and reliability in straight line walking. Table 1 shows the median and range (minimum and maximum) of the observed and pedometer step counts worn at the left hip, right hip and back for each gait speed. Table 2 shows the range of percentage differences between observed steps and pedometers worn at the left hip, right hip and back. The median (range) velocities for slow walking, normal walking and running were 0.64 (0.32, 1.04), 0.91 (0.60, 1.38) and 1.81 (1.38, 1.93) m s^{-1}, respectively.

When investigating paired differences between observed and pedometers step counts, significant heterogeneity was found in the variances of observed—right measurements over gait speed (slow walk, normal walk and running) (Bartlett's test, $p = 0.01$) indicating that the objective measurements were dependent on gait speed. While not statistically significant, heterogeneity appeared to be evident in the observed—left (Bartlett's test, $p = 0.11$), and observed—back (Bartlett's test, $p = 0.18$) measurement differences over gait speed. Lowess curves on the Bland—Altman plots of observed and pedometers step counts failed to show any consistent non-linear pattern over the

mean difference step count range (not shown) and clustered regression analysis revealed no significant difference in mean difference values between gait speed categories for the observed—left analyses ($p = 0.06$), observed—right analyses ($p = 0.42$) or the observed—back analyses ($p = 0.54$). This indicates that any systematic bias between observed and pedometers step counts is not dependent on pace. With the small sample size, however, the power to detect significant differences between groups is relatively small. Because of the small sample size and the heterogeneous variances, each pedometer site was examined separately over each gait speed.

Fig. 2 shows the estimate of the bias and associated 95% limits of agreement for each pedometer site and gait speed relative to the directly observed steps. Limits of agreement were narrowest for running and widest for slow walking, with widths ranging from 15 pedometer steps (for right hip and running) to 44 steps (for right hip and slow walking). The latter can be interpreted as meaning that when an observed step count of 60 is recorded on a slow walking preschool child, in 95% of instances the right hip located pedometer will record a step count between 38 and 82 steps.

Discussion

The first stage of this study involved assessing the validity of pedometers using direct observation as

Table 2 Median and range (minimum and maximum) of relative percentage differences between observed steps and pedometer steps by pedometer site and gait speed

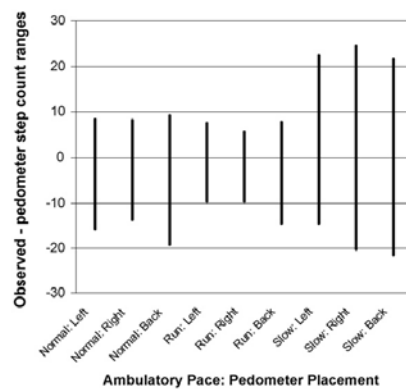| Gait speed	Observed—left (percentage difference)		Observed—right (percentage difference)		Observed—back (percentage difference)	
	Median	Minimum, maximum	Median	Minimum, maximum	Median	Minimum, maximum
Normal	5	−5, 25	5	−7, 23	6	−10, 40
Running	5	−10, 14	5	−10, 16	12	−13, 17
Slow walk	−8	−23, 20	−1	−31, 23	3	−24, 25
Combined	3	−23, 25	5	−31, 23	5	−24, 40

Figure 2   Ninety-five percent limits of agreement for difference between observed step counts and pedometer step counts by ambulatory gait speed, and pedometer placement for preschool children walking in a straight line over 29 m.

the criterion measure. Correlations observed in the current study were similar to those found in the larger study of Louie and Chan[13] ($r = 0.59$, compared with $r = 0.64$). McKee et al.[14] found stronger correlations than in the present study ($r = 0.64-0.95$), although pedometer data were collected in 3 min intervals as opposed to steps accumulated for the entire observation period. This methodology was proposed to account for the sporadic nature of children's activity, however, it is unlikely that the Yamax Digiwalker pedometers would be used in this way for research purposes. Aside from the New Lifestyles NL-2000 pedometer (which is capable of sampling in 24 h periods), no pedometers have time sampling capabilities, therefore, collecting data at 3 min intervals would be time consuming and impractical.

Using the approaches of Bland and Altman,[16,18] pedometer accuracy was variable in both stages of the study. In the first stage, the prediction intervals for pedometry were wide. The question thus becomes, does the 95% prediction interval for the pedometer have a width that would be acceptable in the 95% limits of agreement? One approach to answering this question is to try and quantify what would be a meaningful difference in physical activity using a known standard of measurement. Below we have used the CARS measurement units to understand what a meaningful change in physical activity for a preschooler might be and related this back to the errors of measurement we have determined for pedometry.

In terms of direct observation, average CARS activity levels of $3-5 \text{ min}^{-1}$ might be considered physically active, whereas average levels of $1-2$ would be considered inactive or sedentary. In validating the CARS, significant differences were found between activities conducted at a CARS activity level of 2 (e.g., going down a slide), as compared with activities conducted at a level of 3 (e.g., walking at a moderate gait speed). Therefore, an increase in average activity level per minute by 1 (e.g., from level 2 to level 3) could be considered meaningful. As reported earlier, the CARS prediction intervals for pedometry at only 1000 pedometer steps (relative to only 10 min brisk walking in adults[20]) ranged from an average of 1.7 to 3.0 min^{-1} (width 1.3) for the 35 min observation period. Thus, the prediction intervals for these monitors would be considered unacceptable when using changes in CARS activity levels as a criterion for understanding meaningful differences.

It must be noted, however, that a fundamental issue identified in this pilot study was the commonly used and accepted approach of considering direct observation as a criterion measure of physical activity. The researchers noted a number of limitations inherent with this methodology of quantifying physical activity, which are outlined individually below:

The CARS was developed using energy expenditure, not physical activity, as a criterion. While energy expenditure is a consequence of physical activity participation, this is not a direct measure of activity.

Activity coding for the CARS entailed coding activity levels a maximum of once per category during each minute of observation, which may have lead to misrepresentation of activity levels. For example, a child may lie motionless for 3 s in a minute (level 1), then run very quickly around a playground for the remaining 57 s (level 5). The average coding for this minute would be level 3 ($(1 + 5)/2$), when in fact a much greater proportion of activity was spent at a higher level. In other words, if this activity were calculated using second-by-second time sampling, the actual level of activity would be 4.8 (($0.05 \times$ level 1) + ($0.95 \times$ level 5)). One way to mitigate this is to modify the CARS to match the sampling time frame, as has been done with accelerometers (using 15 s time frames),[11] although this approach would still be problematic when assessing pedometry.

While observer training was conducted, direct observation protocols are still inherently subjective and are reliant on observer accuracy and interpretation of activity.

One key purported benefit of using direct observation is the ability to quantify types of activity

participated in (e.g., midline crossing). The CARS approach involves estimation of physical activity level, considering both lower body and upper body movement, but does not provide any descriptive data on the types of physical activities completed.

The second stage of the study was to assess the validity and reliability of pedometers worn at three different sites (left hip, right hip and back) during straight line walking, when compared with step counts from direct observation. Results showed that pedometer variability was significantly dependent on gait speed for the observed—right pedometer measurements. Such variability in pedometer accuracy with walking velocity has been previously reported in adults.[21,22] This phenomenon was also observed between the other pedometer sites and observed measures, however, these interactions were non-significant. It is possible that with a larger sample size, the observed relationships may have been significant.

The 95% limits of agreement were slightly less for both left and right pedometer sites than for the back. When data from all three gait speed conditions were combined, the 95% limits width size for back measurements were around 7% wider than the left and right measurement sites. The most important question then becomes, how much variability is acceptable in terms of accurately assessing physical activity in this population? To date, no studies have utilised pedometry to determine meaningful differences in preschoolers' physical activity (e.g., in relation to outcomes such as obesity or cardiovascular disease risk), and so it is not possible to answer this question with confidence. Tudor-Locke et al.[23] devised daily step guidelines of 12,000 and 15,000 for school-aged girls and boys, respectively, which were based on a reduced risk of being overweight or obese. As preschool children move differently to school-aged children, however, these values are unlikely to be relevant to this younger population. An alternative approach to establishing how much variability is acceptable would be to consider the range of percentage differences between the pedometer and observed steps. As may be observed in Table 2, the range of percentage differences between observed steps and pedometers worn at the left hip, right hip and back were substantial, at 48, 56 and 64%, respectively. Considering this variability occurred whilst walking in a straight line over a relatively short distance (29 m), we propose that this amount of variability is not acceptable.

Two explanations are proposed as to why such variability existed in pedometer results during straight line walking. Firstly, movement (especially walking) patterns of young children may have more horizontal motion than that exhibited by older children, due to their wider base of support during gait development.[24] This may result in different motion sensor readings according to hip placement. It was hypothesised that back placement may be more accurate than placement at either of the hips and may reduce reactivity, as the child cannot see or reach the pedometer. From the current findings, however, we suggest that back placement may result in less accurate data. Secondly, children may have tampered with the belts on which the pedometers were attached during the straight line walking test and such moving the belts horizontally or vertically would have changed the site of pedometer measurement. This situation, however, was highly unlikely, given that each individual child was being observed during the test, and the researcher would have discontinued the test had this occurred. Nonetheless, this issue may be relevant for future research, and so is still considered a limitation of pedometry in general. While pedometers could be secured to the child's clothing instead of a belt, this approach is not possible when children are wearing dresses or overalls. The use of elastic belts is ideal, as they are non-intrusive, and provide a level of consistency of pedometer placement, irrespective of type of clothing worn.

Conclusion

Considerable variability was found in the ability of pedometers to accurately predict physical activity level as assessed with the CARS. Limitations of the CARS direct observation system as a criterion measure for free-living activity have been identified. A fundamental issue is then raised as to how best to assess the accuracy of physical activity measurement tools? Given that the variable of interest is physical activity rather than energy expenditure, it may be that direct observation is the only option. If the CARS (or similar direct observation systems) were to be used for this purpose, the issues identified in this study must be considered, and more frequent time sampling is imperative. The current study findings indicate that pedometers may not measure steps accurately enough for research purposes with children aged 3—5 years. Pedometer accuracy may be dependent on gait speed, irrespective of site placement, and pedometers may be less accurate when worn at the back, compared with the left or right hip.

It is important to note that these findings pertain only to the distances and activities measured in the

current study. Future investigation of whether the 95% limits of agreement for pedometer validity in straight line walking remain essentially unchanged over longer distances (>29 m) would be particularly worthwhile. Of note, these conclusions are in contrast to previous research, which is possibly due to the application of the Bland—Altman methodology instead of the correlational methods more commonly used in physical activity measurement research. The former is proposed as a more appropriate approach to assessing the magnitude of the difference between physical activity measurement tools and to ensure any systematic bias is accounted for. The small sample size limits further definitive exploration, however, the study findings do provide some indicative evidence for patterns to be investigated in future studies.

Practical implications

- Pedometers may not be sufficiently accurate for research purposes with children aged between 3 and 5 years, and instead may be better suited for situations where a general idea of preschoolers' accumulated physical activity is required.
- When using pedometers with children aged 3—5 years, pedometers should be placed at either the left or right hip, rather than at the back of the child.
- If the Children's Activity Rating Scale is used to validate physical activity measurement tools in preschoolers, the collection of data in time-frames more frequent than the 1 min protocol should be considered.

Acknowledgements

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