Exploring the Development and Use of a Sensor Pressure System to Measure Step Counts in Children With and Without Intellectual Disabilities

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A THESIS SUBMITTED TO AUCKLAND UNIVERSITY OF TECHNOLOGY

IN FULFILMENT OF THE DEGREE OF

MASTER OF HEALTH SCIENCE

May 2012

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ATTESTATION OF AUTHORSHIP

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

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ACKNOWLEDGMENT

Firstly, I would like to acknowledge my primary supervisor, Dr Erica Hinckson, for her support and guidance towards achieving this thesis. Throughout this three and a half year academic journey, Erica's ongoing support and advice has been invaluable. Thank you for all your assistance and for encouraging me to never give up.

Secondly, I would like to acknowledge and thank Patrick Wong who has worked so hard on developing the Sensor Pressure System. Thank you also for your efforts with data collection and the time you invested in my research.

I would also like to thank my secondary supervisor, Jeff Kilby, for his guidance for Pat and invaluable knowledge provided towards the project.

Finally, I would like to thank my family and friends for their support and especially my dad, who always believed in me. While I know you cannot read this thesis, I know you have been with me for this whole journey. This thesis is dedicated to you; you have always been my number one supporter and I cannot explain how much it meant to me. I will always love and remember you.

This thesis has received approval from the following ethics committee: Auckland University of Technology (27 May 2011: Ethics Application Number 11/75).

ABSTRACT

Daily physical activity is essential for children's health and wellbeing. Physical inactivity is becoming increasingly evident in children from developed countries. Alongside these declines in physical activity are increased rates of childhood obesity. Children with intellectual disabilities (ID) are at a greater risk for obesity and this risk is associated with inactivity. However, due to measurement difficulties, limited studies have assessed physical activity in children with ID. Their refusal to be instrumented and discarding of devices are just some of the problems commonly encountered by researchers when attempting to objectively measure physical activity in children with ID. The purpose of this thesis was to explore an objective measure of physical activity that is accurate, tolerable and reliable for use in children with ID. The new technology may be employed to monitor trends in physical activity levels and to assess the effects of health interventions.

A Sensor Pressure System (SPS) was the result of a collaborative effort between the AUT Health Science and Engineering Schools. The device consisted of three force sensors, positioned under the inner metatarsal, outer metatarsal and heel, which measured participants' applied weight during walking. Physical activity data were presented in steps. Twenty six children without ID were recruited from intermediate schools and holiday programmes. Nine children with mild ID were recruited from special schools. Out of the 26 typically developing children, ten participated in the test-retest reliability study of the SPS in laboratory conditions, ten participated in the validity study in laboratory conditions and ten participated in the feasibility study in free living conditions. Validity and feasibility of the SPS were assessed against direct observation in nine children with ID during a PE class.

In children without ID the inner metatarsal position displayed the highest reproducibility (ICC = 0.86-0.95). Compared to collection at other positions, data collected by the force sensor on the inner metatarsal were the least likely to contain measurement error. Overall, the SPS was more reliable during slow speeds (ICC = 0.65-0.95). Significant Pearson's correlations were observed between inner and outer metatarsal positions and directly observed steps at all speeds (r =0.84-0.96). Overall, the SPS captured ± 12 % of directly observed steps. Most children without ID wore the

SPS for seven days. Weather, household rules and activity type were the main limitations to the device. In children with mild ID, low Pearson's correlations were observed between the SPS and directly observed steps (*r* =0.13 to -0.37). The SPS underestimated directly observed steps by 8 to 28 % in children with ID. While there were no issues with children refusing to be instrumented, the SPS was not completely inconspicuous, and some children with ID touched the device while it was on their shoe.

The SPS is a valid and reliable measure of physical activity in children without ID. It is a promising tool for use in children with ID. Further work is required for the SPS to become completely inconspicuous, and accurately measure step counts in children with ID.

C/HAPTER 1: INTRODUCTION

BACKGROUND

Physical activity is classified as any bodily movement produced by skeletal muscles which results in energy expenditure (1). Children and young people are recommended to engage in a minimum 60 minutes of moderate to vigorous activity (MVPA) daily (2). Achieving these recommendations will improve cardiovascular health, muscular development and bone health. In addition, through physical activities, children enhance their problem solving skills, engage in team work, are less anxious and feel more confident (2). However, physical activity in children from developed countries appears to be decreasing and sedentary behaviour is increasing (3-8). Sedentary behaviours are those which involve sitting and expend little energy (9) such as television viewing or writing. In the UK only 32% of boys and 24% of girls accomplished 60 minutes MVPA daily (10, 11). In New Zealand only two thirds of young people met these physical activity recommendations (4).

Children's physical fitness also appears to be declining (12). Physical fitness comprises a set of health (general health and well-being) and sport related (the ability to perform sports and general tasks) attributes which assist in performing physical activities (13). Health related attributes of physical fitness include: cardio respiratory endurance, muscular endurance, muscular strength, body composition and flexibility. Performance related attributes consist of: power, speed, balance, reaction time, coordination and agility (13). While strength, speed and power are diminishing in children, cardiovascular fitness is displaying the largest and most rapid decrease at the rate of about 4-5% per decade (12). A positive relationship has been identified between physical activity and physical fitness. While genetics contribute to fitness, daily physical activity patterns will influence physical fitness to a higher degree (14).

Alongside physical activity and fitness declines, the proportion of overweight and obese children is rapidly increasing world-wide (15, 16). These body mass increases are significantly contributing to children's reduction in physical fitness (17, 18). In 2010, 22.5% of New Zealand children were overweight and 13% obese. Being overweight or obese as a child increases the risk of adulthood obesity (19). Consequences of childhood obesity include increased risk of hypertension, dyslipidaemia, chronic inflammation, blood clotting, hyperinsulinaemia, Type 2 Diabetes and glucose intolerance in adulthood (20).

Populations at greater risk of obesity are children with intellectual disability. The risk may be due to lower levels of physical activity, over adequate nutrition, or eating behaviours associated with their disability, medication and chronic health conditions (21-24). In New Zealand, 35,000 of the 90,000 children living with a disability have an intellectual disability (25).

Intellectual disabilities are mental impairments and conditions which limit cognition and prevent participation in daily life (26, 27). Other terms used to describe intellectual disability, are cognitive disability, global developmental delay, mental retardation and learning disability. For the purposes of this document, the phrase "intellectual disability" (ID) will be used. Intelligence Quotient (IQ) tests are considered the most appropriate method for determining ID. Individuals with mild ID have an IQ ranging from 55-69, those with moderate ID have IQ's ranging from 40-54, those with severe ID have IQ's ranging from 25-39 and those with profound ID have IQ's below 25 (27). Examples of syndromes and conditions associated with ID include, but are not limited to, attention deficit/hyperactivity disorder, autistic syndrome disorder, Down's syndrome, fragile X syndrome, and Klinefelter syndrome (28).

Children's weight control programmes tend to focus on increasing daily physical activity levels, reducing sedentary behaviours and improving nutrition. Disability, along with obesity, limits children's participation in many school and social activities (25, 29) and there are few programmes aimed at the management and treatment of childhood obesity which are suited to meet the special needs of children with ID. Auckland District Health Board, in collaboration with Mind Exercise Nutrition...Do it! (MEND) Australia and United Kingdom, piloted a modified MEND programme in special schools in Auckland. The programme aimed to help children living with ID and their families to improve the children's health, fitness, diet and wellbeing (30).

The modified MEND programme successfully improved aspects of participants' nutrition, physical activity, attitudes towards health and socialisation. However, the content of the programme was not always suitable for the special needs of children with

ID (30). Issues encountered with children discarding their motion sensors and refusing instrumentation came to light during programme evaluation. With these measurement difficulties, objectively measured physical activity levels could not be obtained (30).

In typically developing children, objective measures of physical activity are considered more valid and reliable than subjective tools. In addition, with the association between fitness and activity, physical fitness may be used as a proxy marker for physical activity levels. The most accurate objective measures, which are also gold standards of physical activity measurement, include indirect calirometry, doubly labelled water and direct observation (31). Pedometers, heart rate telemetry and accelerometers are additional objective measures of physical activity that have been validated against gold standards. Subjective methods are less accurate and include: proxy reports, logs and questionnaires. Physical fitness is usually assessed objectively, (32, 33) but relies on maximal effort and motivation by participants. A multitude of fitness tests exist that measure cardiovascular endurance, strength, flexibility, muscular endurance, body composition and balance (32, 33). Only a small number of studies have employed fitness tests, objective or subjective measures of physical activity, to capture daily activity in children living with ID (34-40). Furthermore, limited research has evaluated the validity and/or reproducibility of physical activity and fitness assessments in children with ID.

International and national organisations recommend children with ID engage in physical activity (25, 41). However, no specific guidelines exist for this population. Daily physical activity levels need to be precisely quantified and monitored to develop specific guidelines for children with ID. To accurately assess physical activity levels in children with ID, objective measures of physical activity which are tolerable to children with ID need to be developed.

THESIS RATIONALE

Children with ID refusing to wear devices and their lack of understanding are commonly cited problems with measuring physical activity and fitness. There is limited research characterising physical activity in children with ID, which is likely due to these measurement issues. As walking is the physical activity children most often engage in

(42) this research aims to develop a shoe-based Sensor Pressure System (SPS) which accurately measures daily step counts.

The following section describes the choice of participants, tools and statistical techniques employed in this research.

Choice of Literature Review

Up to date reviews on physical fitness and physical activity measurement tools have been conducted on children without disabilities. No current reviews have examined physical fitness and physical activity measures in children with ID. The literature selected for review in this thesis, therefore, was limited to studies based on children with ID.

Choice of Participants

For the reason that some children with ID may not tolerate physical activity measurement devices or understand laboratory testing procedures, the validity and reliability of the SPS in laboratory conditions were examined in children without ID. Laboratory testing was undertaken to ensure that the device showed good validity and reliability. Once this was established, the feasibility of wearing the device for seven days during free living conditions was examined in children without ID. At the same time the validity and feasibility of the device during PE class in children living with ID was assessed.

Choice of Tools

Sensor Pressure System: The SPS measured the applied weight of participants' steps and physical activity data were quantified as total step counts. Step counts are an easily quantifiable and understandable measure of physical activity. Accelerometers measure accelerations of body movements and convert these into counts. Previously developed thresholds allocate these counts into sedentary, light, moderate and vigorous intensity categories (43). While accelerometers can provide intensity and time in physical activity, these measures were not employed due to the complexity of data output (43).

Reliability: The test-retest reproducibility of the SPS measurement was determined. The intention of this research was to evaluate the reproducibility of data from the SPS, not the variation of steps between participants. Thus, SPS measurements were taken at the same speed on three occasions in laboratory settings and compared.

Validity: The accuracy of the SPS was determined. Sensor measured step counts were compared to directly observed steps and pedometers. Direct observation is a criterion measure of physical activity and was used to examine validity of the new technology during treadmill and classroom trials. The Yamax Digiwalker pedometer was also validated against direct observation during treadmill testing. Direct observation correlations between pedometers and sensors were compared. Previous research showed significant validity correlations (r = 0.80-0.92) of the Yamax Digiwalker against the CARS (children's activity rating scale) method of direct observation in children without ID (31). Duncan and colleagues' protocol has been successfully utilised in previous research and was used for this part of the study (44).

Children without ID were requested to complete activity diaries for two weekdays and one weekend day while wearing the SPS over seven days. Activity diaries were chosen as a means of determining type, time and intensity of physical activity. It was intended that data from the diaries would be compared to the data captured by the SPS. As no children correctly completed their activity diaries these were not included in the analysis.

To assess validity of the SPS in children with ID, devices were fitted during a PE class. A PE class was chosen over daily living as children are required to be physically active during this time. Direct observation is a criterion measure of physical activity (31) and therefore children's directly observed steps were compared to steps recorded by the new technology.

Choice of Statistical Techniques

Reliability study: Due to the small sample size and repeated examination of the same variable, the intraclass correlation coefficient (ICC) is the most suited to quantify reliability (45). For reliability studies the ICC is often viewed as the gold standard (45). However, correlation coefficients cannot detect random error and therefore reliability analyses should be supplemented with another measure of reliability, the change in means (46). The change in means will provide information on whether there was a substantial/significant difference between means of tests. Limits of agreement were not used because the values of the limits are based on the sample size and a bias is added even if none is present (46).

Validity study: The agreement between the steps measured by the SPS or pedometers and those measured by direct observation (criterion measure) were determined. The Pearson's correlation coefficient was used to examine the validity of variables (47). The Bland-Altman analysis was not used because it will show systematic proportional bias in the SPS readings if there is substantial random error which may lead to incorrect validity conclusions (48). Percentage errors were also calculated to examine the validity of the SPS. The difference between each sensor position during each different condition (fast pace, slow pace, medium pace and classroom) and directly observed step counts provided values for the calculation of the percentage error (49).

Feasibility: The suitability of the SPS for measuring daily step counts over an extended period of time in children without ID was examined. Semi structured interviews were employed to explore participants' experiences with the SPS, including any functionality or feasibility issues (50). To minimise recall bias, interviews were held with children and their parents/caregivers immediately after completion of the seven day trial.

ORIGINALITY OF THE THESIS

Current measures of physical activity may not be appropriate for characterising daily physical activity levels in children with ID. This is the first study to develop a concealable shoe sensor pressure system which measures daily step counts in children with ID.

PURPOSE

The purpose of this thesis is to provide an accurate, tolerable and reliable alternative objective measure of physical activity in children with and without ID.

The aims of the research were:

1. To determine validity of SPS for measuring step counts (physical activity) in children with and without intellectual disabilities; and

2. To determine reliability of SPS for measuring step counts (physical activity) in children with and without intellectual disabilities; and

3. To investigate the feasibility of the use of SPS for extended periods in children without intellectual disabilities.

SIGNIFICANCE

The SPS may be employed in the future to monitor trends in physical activity levels and to assess the effects of health interventions. Additionally, a dose-response relationship between physical activity and health can be measured to develop specific physical activity guidelines for children with ID.

THESIS QUESTION

What is the degree of validity, reliability and feasibility of the shoe SPS in measuring step counts in children with and without ID?

THESIS ORGANISATION

This thesis consists of five chapters. Chapter Two is the literature review which identifies studies on physical activity and physical fitness in children with ID. Chapter Three describes the methods employed in this study. Chapter Four presents findings of the SPS testing in children with and without ID. In Chapter Five, results are discussed with recommendations for future development made, and an overall conclusion derived. The organisation of chapters in this thesis is presented in Figure 1.1.

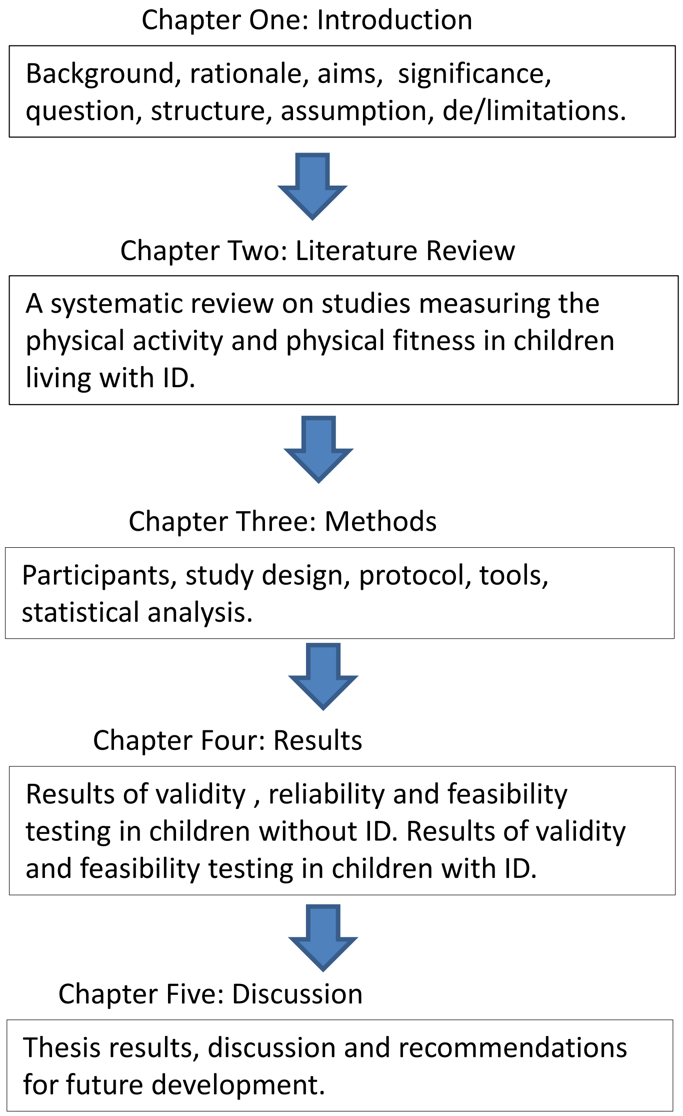

Figure 1.1 The organisation of the thesis

ASSUMPTIONS

The following assumptions were made about the study described in this thesis.

1. Walking is the most common physical activity in which children with intellectual disabilities engage (38).

2. Children with intellectual disabilities wear a favourite pair of shoes constantly throughout the week (51).

3. Children with intellectual disabilities wear shoes while engaging in all activities during their day (51).

(DE)LIMITATIONS

1. Children are only able to wear the same pair of shoes throughout the data collection period (51).
2. Availability of multiple sensors (1-3 sensors available at a time).
3. Limited battery life of sensors restricted measurement time (4-7 days).
4. Limited data collection life of printed circuit boards (4-5 children for 7 days each).

CHAPTER 2: LITERATURE REVIEW

INTRODUCTION

Engagement in regular physical activity is essential for health and wellbeing (2). Evidence suggests that participation during childhood is associated with engagement in physical activity during adulthood (52). Current recommendations advise that children should participate in a minimum of 60 minutes moderate to vigorous physical activity daily (2). Low levels of physical activity have been observed in children from developed countries such as the US, UK, Europe, Australia and New Zealand, and of further cause for concern is evidence that physical activity levels in children continue to decline in these countries (3-8, 10, 11).

Alongside the decline in children's physical activity levels, a world-wide decrease in children's fitness has been evident (17, 18). Regular participation in physical activity will improve or maintain an individual's physical fitness(12). Physical fitness consists of attributes which relate to an individual's ability to perform physical activities (13). These attributes include body composition, muscular and cardio respiratory fitness (13). While genetic factors influence physical fitness, evidence suggests an individual's intensity and total physical activity levels more significantly contribute to fitness (12-14, 53).

Physical fitness and activity inequalities exist between children with and without ID. In particular, children living with ID appear to possess lower levels of cardiovascular fitness, lower maximal heart rates, reduced muscular development and higher body fat levels than children without ID (54, 55). These health disparities may be the consequence of more sedentary lifestyles, fewer opportunities for physical activity, or lower motivation for expending maximal effort during exercise (56, 57). Physical inactivity in this population has been associated with overweight and obesity (24, 58). Health issues linked to obesity in children with ID include chronic conditions such as hypertension, hyperlipidemia, and the development of Type II diabetes. Obesity in children with ID is also associated with the development of secondary conditions related to the child's primary disability. These secondary conditions include difficulty participating in activities of daily living, fatigue, pain, social isolation, depression and perceived cognitive and athletic inability (58, 59). Reducing physical inactivity and increasing fitness in children with ID may aid in weight control and improve the health issues these children face.

It is recommended that children with ID engage in physical activity (25, 41). However, there are no specific guidelines for this population and little evidence exists on current daily physical activity levels and fitness in children living with ID. A recent review reported mixed results, with lower, similar or higher activity levels of children with ID compared to their typically developing peers (60). Furthermore, a review on health related physical fitness and responses to training in youth with Down's syndrome identified this population as having lower strength and cardiovascular capacities compared to their typically developing peers (61). Findings were inconclusive as to whether mild aerobic training improved aerobic capacity in this population (61).

Daily activity levels in children with ID need to be accurately quantified and monitored to identify trends and develop appropriate guidelines. This way focused activity promotion efforts are likely to be more successful. In populations without ID, objective measures of physical activity, including pedometers, heart rate monitors, accelerometers and direct observation are considered more valid and reliable than subjective measures (31). When assessing larger populations, subjective methods of self and proxy reports may be more suitable due to lower cost and less researcher burden (31). Due to the positive relationship between physical activity and physical fitness (14), attributes of physical fitness may be used as proxy markers of physical activity. However, the validity and reproducibility of these subjective and objective tools for characterising daily physical activity levels in children with ID are unknown. Furthermore, no research has directly compared physical fitness with physical activity in children with ID.

It is unclear which are the most appropriate tools for characterising physical activity and physical fitness in children with ID. Therefore the primary purpose of this systematic review is to report on studies measuring the physical activity and physical fitness in children living with ID and summarise the findings.

METHODS

Using three electronic databases (MEDLINE, Scopus, and CINAHL), a literature search was conducted of papers (up to April 2012) on the physical activity and physical fitness in children and youth living with ID. The following key terms were used: "child" or "adolescent" or "youth", "intellectual disability" or "cognitive disability" or "learning disability" or "mental retardation" or "developmental disability, "physical activity" or "exercise", "physical fitness" or "cardio respiratory endurance" or "muscular endurance" or "muscular strength" or "body composition" or "flexibility". Each search was limited to articles from peer reviewed journals, published from 1990 to present, and written in English. The reference lists of published relevant reviews were also searched. All titles, abstracts and full texts of eligible studies were assessed. The literature search is summarised in Figure 2.1.

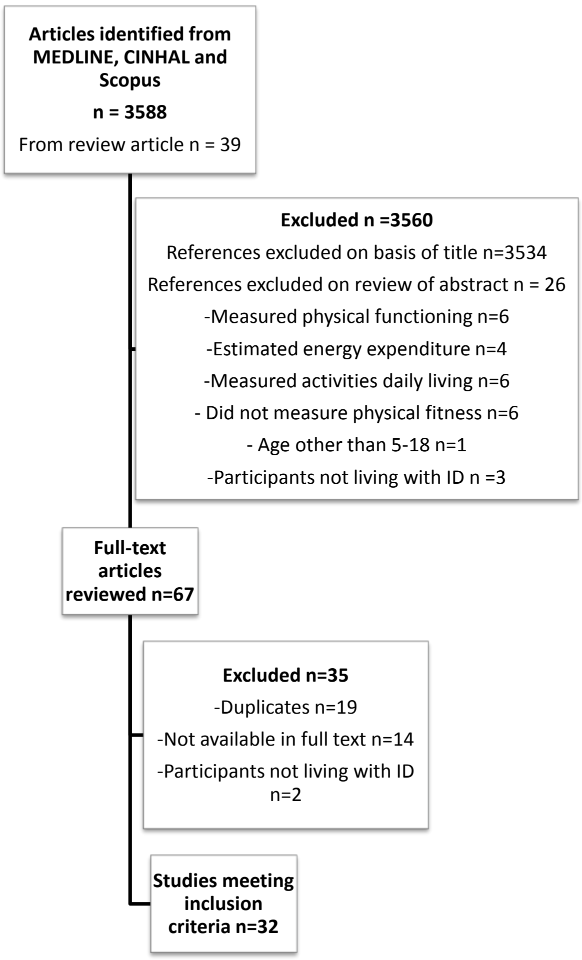

Figure 2.1 Summary of literature review search

Inclusion and Exclusion Criteria

The review was restricted to published research which measured physical activity levels or physical fitness in school age children (5-18 years) living with ID. Studies were excluded based on the following criteria: (1) energy expenditure was measured and related to basal metabolic rate, (2) only motor or functional skills were assessed, (3) the majority of participants were at an age other than 5-18 years, (4) the study focused on physical activity therapy, (5) the study reported on sport performance, and (6) participants were living with cerebral palsy (which is mainly a physical disability) or Asperger's syndrome (which is primarily a behavioural disorder). Studies which only assessed participants' body mass index or skin folds were also excluded as body composition can be largely influenced by diet.

Data Extraction

Results from identified studies were reported using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement (62) and the Cochrane Handbook of Systematic Reviews for Interventions as a guide (63). Data were abstracted onto a standardised form which was developed from the Cochrane checklist of items to consider in data collection or data extraction (63). The following data were abstracted: source, eligibility, methods (design), population (age, gender, disability), instrument (type of fitness test, objective measure of physical activity, subjective measure of physical activity), outcome measure (cm, seconds, total number, mm, counts, minutes, per cent time, steps, beats, energy expended) result and study conclusions. The main attributes and characteristics of the included studies are presented in Tables 2.1-2.2 respectively. Table 2.1 was organised alphabetically by first author and when more than one study was conducted by the same author, by date and title.

Table 2.1 Results of literature search

Initial Author	Participants; mean age ± SD	Instrument	Unit of Measurement	Results
Physical Activity Studies				
Beets and Pitetti 2011 (64)	38 children and adolescents with ID; girls:10, boys:18; mean age 12 ± 2 years.	DO, HRM (S410 Heart Rate Monitor)	Step counts and HR	Children with ID need to walk at a speed of 122 steps/minute to be classified as engaging in MVPA. No validity or reliability data collected.
Eiholzer et al. 2003 (34)	17 children and adolescents with PWS; girls:8, boys:8; mean age 10.5 years. 18 typically developing children and adolescents; girls: 8, boys: 10; mean age 11.1 years.	Pedometer (Mechanical Pedometer) and Diaries	Step counts and activity protocols	Children with PWS were less active at baseline than typically developing children. Post intervention, children with PWS displayed a greater increase in physical activity levels than typically developing children. No validity or reliability data collected.
Faison-Hodge and Porretta 2004 (35)	38 children without disabilities and 8 children with mild MR; girls: 21, boys: 25; mean age 9.2 ± 1.2 years.	DO, HRM (Polar Vantage XL)	SOFIT categories and HR	Children engaged in significantly more MVPA during recess than PE. The mean Pearson's correlation between HRM and SOFIT was r=0.81 during PE sessions and r=0.69 during recess session.
Foley et al. 2008 (65)	9 children with ID; girls: 3, boys: 6; mean age 10 ± 2 years. 33 children without ID; girls: 14, boys: 19; mean age 9 ± 1 year.	Accelerometer (Actiwatch AW 16)	Accelerometer counts	PA levels for children with ID were significantly lower over the weekend, after school, during recess and PE than children without ID. No validity or reliability data collected.
Foley and McCubbin 2009 (36)	9 children with ID; girls: 3, boys: 6; mean age 10 ± 2 years. 9 children without ID; girls: 3, boys: 6; mean age 10 ± 1 year.	Accelerometer (Actiwatch AW 16), parent after school log	Accelerometer counts and after school log	Screen time was positively associated with PA in children with ID. Screen time and PA was negatively associated in children without ID. Children with ID spent more time watching TV per day than children without ID. Children with ID spent less time engaged in computers than

				children without ID. No validity or reliability data collected.
Fragala-Pinkham et al. 2010 (66)	16 children with disabilities; girls:6, boys: 10; mean age 9 years 7 months.	Physical Activity Questionnaire (parent report)	Days per week, type of activity	On average children were active for 2 days more per week post intervention. Swimming was the children's most popular activity. No validity or reliability data collected.
Horvat and Franklin 2001 (57)	23 children with MR; mean age 9.40 ± 2.02 years.	HRM (Polar Vantage XL), accelerometers (Tritrac –R3D), DO	HRM, accelerometer counts and SOAL checklist	Children were more active during recess than the classroom. No validity or reliability data collected.
Jobling and Cuskelly 2006 (67)	38 children with DS and their families; girls: 17, boys: 21; mean age 15 years and 5 months ± 2.29 years.	Interviews	Hygiene, healthy eating, exercise, substance use	Ninety percent of parents reported that their family engaged in weekly exercise, with swimming and running/jogging the most regular activities. Swimming was reportedly engaged in by 69% of children, with walking the next most popular exercise. No validity or reliability data collected.
Kim and Yun 2009 (68)	16 children with ID; girls: 3, boys: 13; mean age 17 ± 3 years.	Accelerometer (Actiwatch), pedometer (Omron HJ-112)	Step and accelerometer counts	Primary sources of variability in accelerometers and pedometers were related to the person and the person by day interaction components. Using pedometers four, six, and eight days of measurements were required to determine typical PA levels of children with ID during weekdays, weekends and full weeks respectively. Using accelerometers four days were required to determine PA during weekdays, weekends and full weeks. No validity or reliability data collected.
Kozub 2003 (69)	7 adolescents with MR; girls:3, boys: 4; between 13-25 years of age.	Accelerometer (RT3), DO, Parent Interview	Accelerometer counts, Children's Physical Activity Form	In general, children were most active after 3pm. Children tended to engage in 6 to 14 bouts of moderate physical activity per day lasting between 2 to 4 min. An inverse relationship between age and physical activity levels was identified. No validity or reliability data collected.
Lin et al. 2005	350 adolescents with ID;	Parent Proxy Report	Preference, prevalence and	29.9% of adolescents had regular physical

(38)	girls: 139, boys: 211; mean age 17.6 ± 0.76 years.		frequency regular physical activity	activity habits. Main physical activities of adolescents were walking, sports and jogging. Only 8% met the Taiwanese guidelines which recommend at least 30 minutes of exercise 3 times per week. No validity or reliability data collected.
Pan et al. 2011 (70)	19 boys with Autism; mean age 14.9± 0.82. 76 boys without Autism; mean age 14.10 ±0.8.	Accelerometer (GT1M Actigraph)	Accelerometry counts	Steps per minute for children with Autism were significantly lower than the boys without Autism. No validity or reliability data collected.
Pitetti et al. 2011 (71)	52 children with DD; girls:16, boys: 36; aged between 6-21 years.	Pedometer (Walk4Life)	Total step counts, activity time and time spent in MVPA	Mean total daily steps were 3392 ± 1474 for boys and 2527 ± 915 for girls. Mean total activity time was 34.2 ± 14.6 minutes for boys and 26.3 ± 9.2 minutes for girls. Mean time spent in MVPA was 6.7 ± 5.8 minutes for boys and 4.3 ± 3.5 minutes for girls. No validity or reliability data collected.
Pitetti et al. 2009 (28)	15 children with mild ID; girls: 9, boys: 6; mean age 9 ± 2 years.	HRM (S410 Heart Rate Monitor)	HR	Children engaged in 83.5 minutes of MVPA during PE, classroom and recess. ICC for resting heart rate was 0.99. No validity data collected.
Pitetti et al. 2009 (49)	24 children with ID; girls: 13, boys: 11; mean age 14 ± 3 years.	Pedometer (Walk4Life 2505), DO	Step counts	Pedometers underestimated steps by 14% and overestimated time by 8.7%. No validity or reliability data collected.
Shields et al. 2009 (72)	23 children with Down Syndrome; girls: 7, boys: 16; mean age 11.7 ± 3.1 years.	Accelerometer (RT3)	Accelerometry counts	On average children engaged in 104.5 min (SD= 35.3 min) MVPA daily. Only 42.1% children participated in 60 min MVPA daily. Older children engaged in lower levels of physical activity than younger children. No validity or reliability data collected.
Sit et al. 2002 (73)	237 children with physical disability, visual impairment, hearing impairment, mild mental disability or	Questionnaire	Physical activity and sport	Girls were significantly less active than boys. Children with physical disability, mental disability and visual impairment were less active than children with hearing impairment and maladjustment.

	maladjustment; girls: 94, boys: 143; mean age 13.5 ± 1.99 years.			No validity or reliability data collected.
Sit et al. 2007 (39)	172 children living with disabilities; grades 4-5.	DO	SOFIT	On average children engaged in MVPA for 7.8 minutes during PE and 8.9 minutes during recess. No validity or reliability data collected.
Sit et al. 2008 (74)	2 schools; 80 children with ID; girls: 26, boys: 54; Grade 4: 25, Grade 5: 20, and Grade 6: 35.	DO	SOFIT	Children in the high sport focus school engaged in PA at a greater intensity. Children in the low sport focus school engaged in more minutes of total activity. No validity or reliability data collected.
Suzuki et al. 1991(40)	802 deaf, blind, MR or physically handicapped students; girls: 329, boys: 473; 3-22 years.	Pedometer (AM-5)	Step counts	On average, deaf students took the greatest number of steps daily. Blind and students with MR took a similar number of steps per day. Students with physical disabilities took the least steps per day. No validity or reliability data collected.
Taylor and Yun 2006 (75)	11 children with MR; mean age 10.5 ± 2.5 years.	DO and Accelerometer (Actiwatch)	CARS, SOFIT, Accelerometry counts	SOFIT and CARS had adequate levels of reliability (*r* = 0.98 and 0.75). SOFIT had low (*r* = 0.10) and CARS had moderate (*r* = 0.61) validity.
Van Mil et al. 2000 (76)	17 children with PWS; girls: 10, boys: 7; mean age 11.9 ± 3.4 years. 17 obese control children; girls: 10, boys: 7; mean age 11.3 ± 2.6 years.	Ventilated hood and doubly labelled water	BMR and AEE	BMR and AEE were significantly lower in the PWS group than the obese children group. No validity or reliability data collected.
Westendorp et al. 2011 (77)	156 children with mild and borderline ID; girls: 52, boys: 104; mean age 9.5 ± 1.5 years. 255 typically developing children;	Self-report questionnaire	Sports participation and sports club membership	Fifty six children with ID participated in sport at least once per week. Children with ID were significantly less likely to participate in organised sport than typically developing children. Soccer and gymnastics (respectively) were the most popular sports engaged in bychildren with ID.

	girls: 117, boys: 138; mean age 9.7 ± 1.3 years.			The reliability and validity of the questionnaire had been tested in a pilot study. The test-retest reliability of the question 'membership of a sports club' was 'very good'. No other validity or reliability data was reported.
Whitt-glover et al. 2006 (55)	28 children with DS and 30 siblings; girls: 28, boys: 28; mean age 7.1 ± 2.1 years.	Accelerometry (Actitrac Accelerometer)	Accelerometer counts	Children with DS engaged in less VPA than their siblings (49.5 vs. 68.6 minutes per day) and for shorter bouts (2.5 vs. 5.1 minutes per bout). Children with DS and their siblings spent similar time in MPA and low-intensity PA. No validity or reliability data collected.
Physical Fitness Studies				
Fernhall et al. 2000 (78)	17 children with MR; girls: 8, boys: 9; mean age 13.7 years.	Max treadmill protocol and 20-m shuttle run	Vo2 max	The 20-m shuttle run is a valid measure of peak oxygen uptake in children with MR. Measured peak oxygen uptake and predicted oxygen uptake from shuttle run test r=0.86. No reliability data collected.
Foley et al. 2008 (79)	421 students with MR; girls: 134, boys: 287; aged between 13 to 18 years.	800-m run test, sit up test, upper arm and shoulder girdle strength test, sit and reach test	Seconds, total sit ups, cm	No significant differences were found between gender and disability level. Health related fitness significantly contributed to decreased body fat. No validity or reliability data collected.
Fragala-Pinkham et al. 2006 (80)	28 children with neuromuscular or developmental disabilities; girls: 11, boys: 17; mean age 9.1 ± 2.32 years.	Muscle strength (Chatillon® hand held dynamometer), HR (Polar® heart rate monitor), Presidential Physical Fitness test (one mile walk/run, shuttle run, sit-ups, push-ups, and sit and reach)	Peak isometric muscle strength, RHR, total sit-ups and press-ups, cm, time, laps	Significant improvements were found on all fitness and strength tests. The effect size was large for the Pompe-PEDI and moderate to small for the other outcome variables. No validity or reliability data collected.
Frey and Chow 2006 (81)	444 youth with mild ID; girls:180, boys:264; aged 6-18 years.	6- (ages 6–8 years) or 9- (ages 9–18 years) minute run, sit-up, isometric push-up, sit and reach, and sum of skinfold	Metres, total sit ups, total push ups, cm, mm	BMI was weakly correlated with the run and push up tests. In all tests excluding the sit and reach test, age and gender accounted for the most variance. No validity or reliability data collected.
Guerra et al. 2009 (82)	19 adolescents with DS; girls: 7, boys: 12;	Wingate Anaerobic test	30s Stationary Cycle	Adolescents with DS performed poorly on the WAnT. The reliability of WAnT is questionable

	mean age 14.8 ± 3.01 years.			in this population. Mean anaerobic power was 158.72 W and 168.71 W on the first and second test respectively, with an ICC of *r* = 0.86 (*p* <0.05). Peak power was 210.37 W and 236.26 W on the first and second test, respectively, with an ICC of *r* = 0.93 (*p* < 0.05). There was a significant difference in peak power between tests (*p* < 0.05). The time to peak power was 6.67s and 6.28 s on the first and second test respectively, with an ICC of *r* =0 .69 (*p* < 0.05). No validity data collected.
Lewis and Fragala-Pinkham 2005 (83)	One 10.5 year old girl with DS.	Cardiovascular function, body dimensions, flexibility, gross motor skills, anaerobic power test, and muscle strength and endurance	Oxygen uptake, height and weight, sit and reach test, ankle dorsiflexion with knee extension, Apley scratch test, goniometric measurements of hip internal rotation, Gross Motor Scales of the Bruininks-Oseretsky Test of Motor Proficiency, Margaria- Kalamen power test, timed sit ups, back extensors, shoulder flexion and abduction; hip extension, adduction, and abduction; and knee extension bilaterally	The participant's HR (*p* = 0.008) and RR (*p* = 0.038) were significantly lower post training. Her body mass index and VO2 did not significantly change. Flexibility results were within normal limits for the sit and reach test, ankle dorsiflexion with knee extension, and Apley scratch test. Her anaerobic power increased by about 60 % as measured by the modified Margaria-Kalamen power test. Strength gains were observed in all measurements for the trunk and upper and lower limbs (*p* = 0.014). No validity or reliability data collected.
Pitetti and Fernhall 2004(84) (1)	325 children with mild MR without DS; girls:151, boys: 244; aged 11-18 years. 119 adolescents with DS; girls: 57, boys: 62.	20-m shuttle run	Laps	Male and female participants without DS completed more laps than those with DS. Male participants with and without DS completed more laps than female participants. No validity or reliability data collected.
Pitetti and Fernhall 2004(84) (2)	80 youth without MR; girls: 39, boys: 41; age, height and weight matched from a selection of children from (1).	20-m shuttle run	Laps	Male and female participants without MR completed more laps than their peers with MR, with and without DS. No validity or reliability data collected.
Skowro'nski et al. 2009 (85)	545 children with mild ID;	Explosive leg strength (Long jump), 2 kg medball push, 30s	Metres, total times pushed, total sit ups, seconds, cm, flexibility	In general individuals with mild ID performed better in fitness tests than those with moderate

	girls: 177, boys: 368. 835 children with moderate ID; girls: 359, boys: 476. 203 children with severe ID; girls: 92, boys: 111. aged 8- 22 years.	sit up, 25m run, sit and reach, bench walk		and severe ID. Overall, boys performed better in fitness tests than girls. Older individuals tended to perform better in fitness tests than younger children. No validity or reliability data collected.

ID: Intellectual Disability; DO: Direct Observation; HRM: Heart Rate Monitor; HR: Heart Rate; MVPA: Moderate to Vigorous Physical Activity; PWS: Prada Willi Syndrome; MR: Mental Retardation; SOFIT: System of Observing Fitness Instruction Time; PE: Physical Education; PA: Physical Activity; SOAL: Scheme for Observing Activity Level; DS: Down Syndrome; ICC: Intraclass Correlation Coefficient; CARS: Children’s Activity Rating Scale; BMR: Basal Metabolic Rate; AEE: Activity Energy Expenditure; VPA: Vigorous Physical Activity; MPA: Moderate Physical Activity; RHR: Resting Heart Rate; CM: Centre metres; MM: Millimetres; BMI: Body mass Index; WAnT: Wingate Anaerobic Test; W: Watt.

Quality Assessment

The limited number of studies identified in this systematic review rendered a meta-analysis inappropriate. A modified checklist derived from the Downs and Black Checklist was used to assess quality of studies (Table 2.3) (63). Scores were accumulated and a percentage derived. Quality was defined as good when a study scored between 67% -100%. None of the studies employed a representative sample or had sufficient power to detect a clinically important effect with no probability of chance.

Table 2.2 Characteristics of studies reviewed (N=32)

Characteristics	References	Number (%) of articles
Physical Activity Behaviour		
Daily/Weekly total	(34, 40, 55, 65, 68, 69, 72)	7 (22%)
Sport	(73, 77)	2 (6%)
School	(28, 35, 39, 49, 57, 74, 75) (70, 71)	9 (28%)
Out-of-school/leisure	(36, 38, 64, 66, 67, 73)	6 (19%)
Energy expenditure	(76)	1 (3%)
Physical Fitness Measure		
Cardiovascular Fitness	(78-85)	8 (25%)
Muscular Strength	(79-81, 83, 85)	5 (16%)
Muscular Endurance	(79-81, 83, 85)	5 (16%)
Flexibility	(79-81, 83, 85)	5 (16%)
Balance	(85)	1 (3%)
Body Composition	(81, 83)	2 (6%)
Type		
Questionnaire	(66, 73, 77)	3 (9%)
Interview	(67, 69)	2 (6%)
Report/diary	(34, 36, 38)	3 (9%)
Objective	(28, 34-37, 39, 40, 49, 55, 57, 64, 68, 72, 74-76)	18 (56%)
Physical Fitness	(78-85)	8 (25%)
Reliability		
Reliability assessed	(75, 77, 82, 84)	4 (12%)
Validity		
Validity assessed	(35, 75, 78)	3 (9%)
Geographic location		
Asia	(38, 39, 55, 73, 74, 79, 81)' (70)	8 (25%)
Australia	(67, 72)	2(6%)
Europe	(34, 66, 76, 77, 80, 82, 85)	7 (22%)
North America	(28, 35, 36, 40, 49, 57, 64, 65, 68, 69, 75, 78, 83, 84)' (71)	15 (47%)
Year of publication		
1990-1999	(40)	1 (3%)
2000-2005	(34, 35, 57, 69, 73, 76,	9 (28%)

	78, 83, 84)	
2006-2011	(28, 36, 38, 39, 49, 55, 60, 64-68, 72, 74, 75, 77, 79, 80, 82, 85)' (70)' (71)	22 (69%)

RESULTS

Overall, 3588 references were retrieved from the data base search and a further 39 identified from other sources. After screening, 32 studies were reviewed of which 24 studies measured the physical activity of children with ID and eight studies assessed children's physical fitness (Table 2.1). Table 2.2 shows the characteristics of these studies. The majority of research was rated as 'good' with the rest 'satisfactory' (Table 2.3).

Table 2.3 Quality score for studies investigating physical activity in children and youth with intellectual disabilities

	Reporting						External Validity	Internal validity		Power	Score	Descriptor
	Clear hypothesis/aim/objective	Clear main outcomes to be measured	Clear participant characteristics for inclusion	Clear study description	Clear description of main findings	Actual probability values reported (except p<0.001)	Representative sample	Appropriate statistical test	Valid and realiable outcome measures	Sufficient power to detect a clinically important effect where the probability value for a difference being due to chance is less than 5%	%	0% -33% , Bad; 33%- 66%, Satisfactory; 67% - 100%, Good
Beets and Pitetti (64)	X	X	X	X	X	NA		X	X		77	Good
Borremans et al. (42)	X	X	X	X	X	X		X	X		80	Good
Eiholzer et al. (34)	X	X	X	X	X			X	X		70	Good
Faison-Hodge and Porretta (35)	X	X	X	X	X	X		X	X		80	Good
Fernhall et al. (78)	X	X		X	X			X	X		60	Satisfactory
Foley et al. (79)	X	X	X	X	X			X	X		70	Good

Foley et al. (65)	X	X	X	X	X	X		X	X		80	Good
Foley and McCubbin (36)	X	X	X	X		X		X	X		70	Good
Fragala-Pinkham et al. (80)	X		X	X	X	X		X	X		70	Good
Fragala-Pinkham et al. (66)	X	X	X	X	X	X		X			70	Good
Frey and Chow (81)	X	X	X	X	X	X		X	X		80	Good
Guerra et al. (82)	X	X	X	X	X			X	X		70	Good
Horvat and Franklin (57)	X	X	X	X	X	X		X	X		80	Good
Jobling and Cuskelly (67)	X	X	X	X	X	Na					50	Satisfactory
Kim and Yun (68)	X	X	X	X	X	Na		X	X		77	Good
Kozub (69)	X	X		X		Na			X		44	Satisfactory
Lewis and Fragala-Pinkham (83)	X	X		X	X	X		X			60	Satisfactory
Lin et al. (38)	X	X			X	X		X	X		60	Satisfactory
Pan et al.(70)	X	X	X	X	X			X	X		70	Good
Pitetti et al.(71)			X	X	X	Na			X		44	Satisfactory
Pitetti and Fernhall (84)	X	X	X	X	X			X	X		70	Good
Pitetti et al. (49)	X	X	X	X	X	X		X	X		80	Good
Pitetti et al. (28)	X	X	X	X	X	Na		X	X		77	Good
Shields et al. (72)	X	X	X	X	X	X		X	X		80	Good
Sit et al. (73)	X	X		X	X	X		X			60	Satisfactory
Sit et al. (39)	X	X		X	X	X		X	X		70	Good
Sit et al. (74)	X	X		X	X	X		X	X		70	Good
Skowro’nski et al. (85)	X	X	X	X	X			X			60	Satisfactory
Suzuki et al. (40)	X		X	X	X	X		X	X		70	Good
Taylor and Yun (75)	X	X	X	X	X	Na		X	X		77	Good
Van Mil et al. (76)	X		X	X	X			X	X		60	Satisfactory
Westendorp et al. (77)	X	X	X	X	X	X		X			70	Good
Whitt-glover et al. (55)	X	X	X	X	X	X		X	X		80	Good

Study Characteristics

Thirteen out of the 24 studies measuring physical activity in children with ID were conducted in North America, four in Europe, five in Asia, and two in Australia. Fourteen studies were published between 2006 and the present, with only one published prior to 1999. The research included exploratory, comparative, assessment, validity and/or reliability studies, ranging in size from seven to 450 participants (Table 2.1). Twenty three studies used convenience sampling to recruit participants. Seventeen studies used objective measures of physical activity (28, 34-37, 39, 40, 49, 55, 57, 64, 68, 72, 74-76) (70, 71), five used subjective measures (66, 73, 77) and three employed both (34, 36, 69) (Table 2.2). Accelerometers were the objective measurement tool of choice and questionnaires were the most popular subjective tool. Only four studies reported on the validity or reproducibility of the instruments used to measure physical activity in children living with ID (35, 49, 75, 77).

Three out of the eight studies investigating physical fitness in children with ID were conducted in Europe and three in America, with the remaining two conducted in Asia. All studies were published later than 2000 with the majority published from 2006 to the present. The research included exploratory, comparative, assessment, case study, validity and/or reliability studies, ranging in size from one to one thousand three hundred and eighty participants (Table 2.1). Convenience sampling was the predominant recruitment method. Cardiovascular fitness was the most common measure of physical fitness, although the majority of studies assessed more than one element of physical fitness (Table 2.2). Only two studies calculated the validity or reproducibility of tests (78, 82).

Objective Measures of Physical Activity

Actiwatch, Actitrac, Actigraph, Tritrac –R3D, and RT3 accelerometers were employed to characterise physical activity in children with ID (36, 37, 55, 57, 65, 68, 75). Shields (72) identified that children with ID engaged in an average of 104.5 minutes MVPA daily and that older participants engaged in less daily physical activity than younger participants. However, only 42.1% of children in Shields' (72) study achieved the recommended 60 minutes of MVPA daily (72). Whitt Glover (55) found that children with Down's syndrome engaged in similar levels of MVPA compared to their unaffected siblings. However, the same children participated in less vigorous physical activity for shorter durations than those siblings. By contrast, Pan et al. (70) found that children with Autism were less physical activity during PE compared with children without Autism (70). Foley (65) discovered that children with ID engaged in significantly lower levels of physical activity over the weekend, after school, during recess and PE, compared to children without ID (65). In further research, comparable amounts of after school screen time behaviours were engaged in by children with and without ID. A significant moderate relationship between screen time (82 ± 68 minutes) and after school physical activity (135.28 ± 43.99 counts) for children with ID (p= 0.04) was detected compared to a negative relationship in children without ID. The positive relationship suggests that the more a child with ID was engaged in screen time, the more physically active they were (36). When using the Tritrac –R3D accelerometer Horvat identified that children engaged with more activity during recess than in the classroom (57). Using RT3 accelerometers in adolescents with mental retardation, Kozub (37) identified that participants were most active after school and tended to engage in six to fourteen bouts of MVPA daily lasting between two to four minutes (37). Kim and Yun (68) concluded that when researching with Actiwatch accelerometers worn on the wrist of youth with developmental disabilities, four days of measurements were required to determine typical physical activity levels during weekdays, weekends and full weeks. No studies determined the validity and/or reliability of accelerometers for children with ID.

Six studies used direct observation to investigate physical activity in children with ID (35, 37, 39, 57, 74, 75). SOFIT (System for Observing Fitness Instruction Time) was the observational tool of choice; however, CPAF (Children's Physical Activity Form), SOAL (Scheme for Observing Activity Level) and CARS (Children's Activity Rating Scale) were also employed. Beets (64) observed that children with ID were required to walk at 122 steps per minute to be classified as engaged in moderate-vigorous physical activity (MVPA). As recorded by SOAL, Horvat (57) concluded that children with ID were more active during recess than in the classroom. Findings by Faison-Hodge (35) and Sit (39) confirm these results. Children with mild mental retardation engaged in significantly more MVPA during recess than PE (35). Overall, children participated in little MVPA during PE (7.8 min) and recess (8.9 min) (39). Further work by Sit (74) discovered that children with ID attending a high sport focus school engaged in physical activity at a higher intensity compared to those attending a low sport focus school. However children in the low sport focus school performed more minutes of total activity (74).

Only three studies assessed the validity and/or reliability of observational tools in children with ID. Against heart rate monitoring, SOFIT correlations were high for PE sessions (*r*=0.81) and moderate for recess session (*r*=0.69) (35). Faison-Hodge (35) also identified high inter-rater reliability (*r*=94.4) for SOFIT. In comparison, and against accelerometry, Taylor (75) detected low validity for SOFIT (*r*=0.10) and moderate for CARS (*r*=0.61) (75). However, SOFIT error variances due to trial, rater, and the trial-by-rater interaction were low (0.30%, 0.67%, and 0.44%), indicating high reliability (75). Seven hours of training provided inter-rater reliability of 85 to 93% for CARS (75), the largest error variance was due to rater (31.49%) and the participant-by-rater interaction (15.41%) (64, 75). CPAF displayed moderate validity against accelerometry (*r*= 0.76 between the 97 intervals of physical activity) during videos of fitness testing (69).

Walk4Life 2505, AM-5 or Omron HJ-112 pedometers were used to measure step counts in four studies (34, 40, 49, 68). Eiholzer (34) discovered that children with Prada-Willi Syndrome (PWS) were less active than their typically developing peers. However, after a physical activity intervention, children with PWS displayed a greater increase in physical activity than children without ID. In a large pedometer study students with ID engaged in similar daily steps compared to blind students, fewer steps than those with hearing impairments and greater steps than those with physical disabilities (40). Kim and Yun (68) concluded that the Omron HJ-112 required four, six, and eight days of measurements to determine typical steps during weekdays, weekends and full weeks in youth with developmental disabilities. When assessing children's physical activity on summer camp, Pitetti et al.(71) discovered that on average boys with ID took 3392 steps per day and girls took 2527 steps per day. In addition, the mean total activity time for boys was 34.2 minutes and for girls 26.3 minutes. On average, boys spent 6.7 minutes in MVPA while girls spent 4.3 minutes (71). Only one study determined the validity of pedometers in children with ID. During an adapted physical education class Pitetti et al. (49) discovered that, against direct observation, pedometers underestimated step counts by 14% ± 16.5%.

In three studies heart rate monitors were used to measure intensity of participants' physical activity levels at school (28, 35, 57). Faison-Hodge (35) employed heart rate monitors to validate and confirm SOFIT findings. Heart rate was used by Horvat and Franklin (57), alongside SOAL and accelerometry (as previously described), to assess physical activity during school in children with mental retardation, with similar results detected between measurement tools. Pitetti et al. (28) found that children with ID performed 83.5 minutes of MVPA during PE, classroom time and recess. No studies assessed the validity and/or reliability of heart rate monitors in children with ID. However, using heart rate monitors, Beets (64) discovered that 122 steps/minute was the required threshold for MVPA in children with ID.

One study employed doubly labelled water to determine physical activity energy expenditure (76). Obese children with PWS had significantly lower metabolic rates and activity energy expenditure compared to typically developing obese children (76).

Subjective Measures of Physical Activity

Four studies employed questionnaires to collect physical activity data in children with ID. The children themselves completed questionnaires in the research by Sit (73) and Westendorp (77). Soccer and gymnastics were the most popular activities performed by children with ID (77). Westendorp(77) further identified that children with ID reportedly participated in less sport than typically developing children. When comparing different groups of children with ID from Hong Kong, girls participated in significantly less sport than boys (73). In addition, children with physical disability, mental disability and visual impairment were less active than those with hearing impairment and maladjustment (73). Fragala-Pinkham (66) used parent questionnaires to evaluate the effectiveness of a swimming intervention. Children with ID subsequently engaged in 60 minutes of MVPA five days per week compared to three days pre-intervention (66).

Parent interviews, log books, and diaries were also utilised by researchers to assess physical activity in children with ID. Time use diaries confirmed pedometer results that children with PWS were less active than their typically developing peers (34). Through parent after school logbooks, Foley (36) identified that children with ID engaged in more after school TV viewing and less computer use than children without ID (36).

However, total screen time behaviours were comparable between the two groups. Parent interviews revealed that the majority of families who had children with ID engaged in weekly exercise, and swimming was the most popular activity (67). In contrast, using a parent proxy report, Lin et al. (38) discovered walking, sports and jogging were the most popular activities engaged by Taiwanese adolescents with ID. However, only one third of those adolescents had regular physical activity habits and only 8% met the physical activity recommendations of 30 minutes daily exercise three times per week (38). Kozub (69) also employed parent interviews to confirm objective results which were previously described (69).

One study piloted the validity and/or reliability of questionnaires in children living with ID. However results were reported on one question only, the question related to membership in a sports club, and the test-retest reliability of the question was ‘very good’ (77).

Measures of Physical Fitness

The majority of physical fitness research assessed cardiovascular fitness in children with ID. Foley (79) found no significant difference between gender and children’s disability levels in the 800-m run test. On the other hand, Frey and Chow (81) concluded that gender and age accounted for the most variance in the 6 or 9-minute run test. Results from Skowro´nski (85) confirm these findings. Furthermore, children with mild ID performed better in cardiovascular fitness tests than children with moderate and severe ID. Children with Down’s syndrome completed fewer laps in the 20-m shuttle run than intellectually disabled children without Down’s syndrome, although no differences were identified between gender and age (84). In this study comparisons were also made between children with ID and children without ID. Children with ID completed fewer laps on the shuttle run than their typically developing counterparts (84).

When employing physical fitness measures to assess intervention effects, Fragala Pinkham (80) noted significant improvements in the one mile walk/run and shuttle run test in children with developmental disabilities. Positive results were also displayed in a case study by Lewis (83) in which a young girl with Down’s syndrome participated in a six week home exercise programme which consisted of thirty to sixty minutes moderate- to high-intensity exercise on five to six days per week. The participant demonstrated a significantly lower heart rate (p = 0.008) and respiration rates (p = 0.038) post intervention. However, no significant changes were identified in the participant's VO2 (83). Guerra (82) found adolescents with Down's syndrome performed poorly on the Wingate Anaerobic Test (involving a 30 second stationary cycle).

Other measures of physical fitness identified in this review included: muscular strength, muscular endurance, flexibility, balance and body composition. Most research used cardiovascular fitness tests alongside these measures. Frey (81) conducted sit-up, isometric push up, sit and reach and skinfold tests on youth with ID and only detected a weak correlation between BMI with the run and push up tests. Conversely, Foley (79) employed a sit up test, upper arm and shoulder girdle strength test, and the sit and reach test to compare physical fitness in children with mental retardation and found health related fitness was significantly related to decreased body fat. Muscle strength, heart rate and the Presidential Physical Fitness test (one mile run/walk, shuttle run, sit-ups, push ups, and sit and reach) were also utilised by Fragala-Pinkham (80) to determine the previously noted intervention effects. Children with ID displayed significant improvements on all fitness and strength tests (p=0.001-0.030) after engagement in the 16-week community-based programme, performed bi-weekly and consisting of strengthening, aerobic conditioning, and flexibility exercises (80). Lewis (83) also assessed participants' BMI which did not significantly change post intervention (83). Skowro´nski (85) measured explosive leg strength, medball push, thirty second sit-ups, sit and reach, and the bench walk, alongside cardiovascular measures, to draw the previously discussed conclusions.

Only two studies calculated the validity and/or reliability of physical fitness tests in children with ID. Fernhall (78) concluded the 20-m shuttle run was an accurate measure of peak oxygen uptake in children with MR (r=0.86 compared with max treadmill protocol). However, evidence of the reliability of physical fitness tests in children with ID is limited. In the Wingate Anaerobic Test participants' test-retest mean anaerobic power had moderate-high correlations (with an ICC of r=0.86) and peak power was highly correlated (with an ICC of r=0.93) (82). Although the time to peak power was only moderately correlated with an ICC of r=0.69 (82).

DISCUSSION

This is the first systematic review to report on studies assessing physical activity and physical fitness in children with ID. When characterising physical activity in children with ID and comparing their activity levels to children without ID studies showed mixed results. A range of objective and subjective measures of physical activity were used by researchers, most of which have not been validated or assessed for reliability in children with ID, which may explain the inconclusive results. Mixed results were also reported by studies comparing physical fitness in children with ID. Only one study made comparisons between physical fitness in children with ID and children without ID. Although findings suggest children with ID had lower fitness levels, this evidence is weak due to the lack of high-quality supporting studies. In addition, the limited research comparing physical fitness in children with ID to those without, which is identified by this systematic literature review, makes it difficult to draw accurate conclusions. While it was not the intention of this review to determine the most accurate tool for measuring physical activity or physical fitness in children with ID, the small number of studies identified emphasise the requirement for high quality validity and reliability research in this area.

Objective Measures of Physical Activity

Researchers consider that objective measures of physical activity are more credible than subjective measures (31). Accelerometers are motion sensors that detect accelerations of body movement. Earlier models sensed movement in either horizontal or vertical planes; more sophisticated models may detect motions in multi planes. Accelerations are sampled during an epoch (a set time interval, usually between 15 seconds and one minute) and data are outputted as “counts”. Counts represent the total accelerations per epoch and are classified as sedentary, light, moderate and vigorous intensity categories according to prescribed thresholds. While most accelerometers are valid (r= 0.27 to 0.89) and reliable (ICC=0.49 to 0.98) measures of physical activity in children without disabilities, no studies identified in this review assessed the validity and/or reproducibility of accelerometers measuring physical activity in children with ID (86). However, in studies comparing direct observation, heart rate monitors and accelerometry, all measurement tools had similar results (57). The consistent results of all three measurement tools suggest accelerometers are an accurate tool to measure physical activity in children with ID. In addition, studies utilising accelerometers found children with ID engaged in less physical activity than children without ID (36, 55, 65). This commonality between studies suggests accelerometers may be valid measures of physical activity in children with ID.

Nonetheless, limitations to accelerometry use in children with ID exist. The majority of researchers placed accelerometers on participants' hips, and with gait issues prevalent in children with ID, this may have prevented accurate readings (55). Sedentary, light, moderate and vigorous category accelerometer thresholds were determined in mainstream children. Movement of children with ID tends to be less efficient, with lower maximum oxygen consumption levels compared to children without ID (55). Therefore, accelerometer thresholds used for children without ID may not be appropriate for children with ID (55). Finally, while refusal by some children to wear accelerometer devices was encountered by Shields (72) during data collection, Kim and Yun (68) concluded that accelerometers required fewer days of assessment compared to pedometers when measuring physical activity in children with ID. Kim and Yun's (68) findings suggest that the validity of accelerometers is greater than that of pedometers, but the scarcity of evidence means conclusions cannot be drawn regarding the suitability of accelerometers in children with ID. More research is needed to determine validity and reproducibility of accelerometers in this population. In addition, accelerometer placement on participants with gait issues needs to be considered and appropriate thresholds determined.

Direct observation is a criterion objective measure of physical activity which has been proven valid and reliable in children without ID. In this review, mixed findings were seen in studies determining the validity and reproducibility of SOFIT, CARS and CPAF in children with ID. Consistent with studies in children without ID (87, 88), Faison-Hodge and Porretta (35) concluded SOFIT to be a valid measure of physical activity in children with ID compared to heart rate monitors (35). Conversely, Taylor (75) identified only a weak correlation between SOFIT and accelerometry which indicated low validity (75). Comparisons cannot be made with studies in typically developing children as no research has validated SOFIT against accelerometry. Direct observation is considered a superior measure of physical activity, which suggests accelerometers may not be appropriate for validating SOFIT. The low validity identified by Taylor (75) may be due to accelerometry measurement error rather than SOFIT. However, in the same study CARS and accelerometer correlations were moderate (75) and when CPAF was validated against accelerometry the correlation was moderate (37). It would seem that CPAF and CARS are more accurate measures of physical activity than SOFIT.

High inter-observer agreement identified by studies suggests that the observational tools used in children with ID were reliable (35, 39, 74, 75). SOFIT possessed higher reproducibility than CARS for measuring physical activity in children with ID during a gym-based programme at school. However, high reliability values were obtained after seven hours of rater training. This high researcher burden is one of the limitations of direct observation. Other limitations include the small sample size that can be observed and participants' awareness of being observed, which may alter usual behaviours (89).

Pedometers are worn on the hip and quantify total daily step counts. None of the studies identified in this systematic review assessed the validity and/or reproducibility of pedometers in children with ID. However, most pedometers are valid (r= 0.68 to 0.90) and reliable (ICC=0.51 to 0.96) measures of physical activity in children without ID (90). Compared to accelerometers, pedometers required a greater number of days to characterise physical activity in children with ID (68). In addition, some children with ID refused to be instrumented with pedometers (71). Pitetti (49) evaluated the validity of pedometers against direct observation and concluded that pedometers may not be an appropriate tool for measuring physical activity levels in children (49). More research is needed to determine the validity and reproducibility of pedometers in children with ID.

High heart rate values, as measured by heart rate monitors, equate to high physical activity intensities. Heart rate monitors are a valid and reliable measure of physical activity intensity in children without ID (31). None of the studies identified in this review validated or assessed the reproducibility of heart rate monitors for measuring physical activity in children with ID. As noted earlier, Horvat (57) employed direct observation, accelerometers and heart rate monitors to characterise physical activity in children with ID. Similar findings were identified between all measures which suggests heart rate monitors are a valid measurement tool when measuring physical activity in children with ID. However, refusal to wear the heart rate monitors and children's inability to sit still were issues encountered when using monitors in children with ID

(28). In addition, during sedentary or light activity, heart rate can be affected by stress, excitement, environmental conditions and medication (31). These limitations weigh against heart rate monitoring being a suitable tool for measuring physical activity levels in children with ID.

This systematic review identified one study which employed doubly labelled water to determine physical activity levels in children with ID. Van Mil (76) compared physical activity energy expenditure of children with PWS, corrected for body size, against typically developing obese children (76). Participants drank nonradioactive-labelled isotope ^{2}H, ^{18}O water and elimination of isotopes were tracked for 14 days. The difference between ^{2}H and ^{18}O elimination is equivalent to carbon dioxide production, and from this data energy expenditure was calculated (31). The doubly labelled water method is a criterion measure of physical activity in children without ID as it is accurate, easily used in free-living situations and is often used to validate other instruments (91). While doubly labelled water has not been validated in children with ID, it was used without issues in a study of PWS children (76). However, there are a number of significant limitations to this method which may explain the lack of studies utilising it identified in this review. Only small samples can be measured as the isotopes are expensive, difficult to obtain and those administering must be technically competent. Accurate diet records must be kept and only total energy expenditure can be calculated which means intensity, duration and sedentary behaviour cannot be characterised (91). Due to these limitations, doubly labelled water is not recommended to characterise daily physical activity levels of children with ID.

Subjective Measures of Physical Activity

Subjective measures of physical activity included proxy-questionnaires (38, 66), proxy-activity log (36), activity report completed by parents or older children (34), semi-structured interview with parents (69), and interview-based questionnaires (73, 92). This review only identified one study which evaluated the validity and/or reliability of questionnaires in children with ID and that study only reported on one question relating to membership in a sports club, which had very good test-retest reliability (77). Sit et al. (73) used existing questionnaires that have proven valid and reliable in Hong Kong children without ID. The questionnaire was piloted on five children with mental disability via one-to-one interviews and was found to be valid tool (73). The small sample size used to validate the questionnaire limits the quality of validity results. In children without ID, subjective measures tended to overestimate physical activity as they were limited by memory bias, understanding of questions and knowledge of behaviours (31) . Parental reports have been employed to overcome these issues. However, parents may not possess full knowledge of their children's behaviours. In addition, subjective measures are unable to capture the short bursts of intense activity with long periods of low activity characterised in children without ID. Nonetheless, questionnaires, diaries and proxy reports are inexpensive and quick data collection methods which can be used in large samples of children. Furthermore, parents/caregivers of children with ID often spend a large amount of time with the child during the day and may have a good knowledge of their child's behaviour. Parental/caregiver proxy reports may potentially be useful tools for measuring physical activity in children with ID.

Measures of Physical Fitness

Eight studies assessed physical fitness in children living with ID. The most popular fitness measures were cardiovascular fitness and muscular strength. No research quantified the relationship between physical fitness and physical activity in children with ID. Studies tended to make fitness comparisons between children with ID, children without ID, or used physical fitness to evaluate the effectiveness of physical activity interventions. Improvements were made in most measures of fitness by intervention participants which suggests a positive relationship between physical fitness and physical activity (80, 83).

Few studies quantified the validity and/or reliability of physical fitness measures in children with ID. Consistent with studies validating cardiovascular tests in typically developing children (32), the 20-m shuttle run was an accurate measure of cardiovascular fitness in children with ID ($r=0.86$). However, the Wingate aerobic test was found to be unreliable in children with ID (82). In comparison, health related physical fitness tests, including the back-saver sit and reach, handgrip, standing broad jump, Bosco jumps (squat jump, counter movement jump and Abalakov jump), bent arm hang, 4x10m shuttle run, and 20-m shuttle run tests, have all displayed acceptable reproducibility in children without ID (33). Children with ID may not understand the meaning of maximal effort. This combined with lower motivation than children without

ID may explain why fitness tests were not reliable in this population. Furthermore, some children with ID do not possess the focus, timing, coordination, motor control, or the physical ability, to complete the tests (77, 93, 94). Due to these limitations, physical fitness measures may not be appropriate proxy measures of physical activity in children with ID.

LIMITATIONS

The tools identified in this review for measuring physical activity and fitness in children with ID have had their reliability and validity determined in children without ID (31-33). However, the movement patterns and thought processes of children with ID may differ to children without ID and so measurement tools and thresholds may not be relevant in this population. This systematic review found few studies which validated and assessed the reproducibility of physical activity and fitness measures in children with ID. Future studies should focus on determining the validity and reliability of tools used to assess physical activity and fitness in these children.

Research into physical activity and physical fitness of children with ID was greatly variant in design and methodology which made comparisons difficult. In addition, with the limited information available and mixed results, it is not possible to recommend the most appropriate tool for measuring physical activity or fitness in children with ID.

CONCLUSION

Inconclusive evidence exists on the most appropriate tools for measuring physical activity and physical fitness in children living with ID. Objective measures may be more valid and reliable than subjective measures for characterising physical activity in these children. However, researcher burden coupled with tolerance and gait issues in children with ID may be limitations. Alternative valid and reliable objective options which are tolerable in children living with ID should be explored. The parental proxy report is a promising tool for characterising physical activity levels in this population. However, suitable proxy report tools need to be developed and trialled. Children with ID may not possess the motivation, understanding of or physical ability to effectively complete physical fitness tests. Physical fitness measures therefore may not be appropriate for children with moderate to severe ID.

CHAPTER 3: METHODS

The following section describes the development of the Sensor Pressure System (SPS), the recruitment processes and characteristics of participants, procedures for trialling the device with participants, and data analysis. The SPS was manufactured by the Faculty of Health and Environmental Sciences in collaboration with the Faculty of Engineering at AUT University.

PARTICIPANTS

Children without ID were recruited from mainstream intermediate schools and holiday programmes in North Shore City, Auckland, New Zealand. Permission to access the schools and holiday programmes to recruit participants was provided by School Principals and Centre Management. Information sheets, assent forms and consent forms were sent home with randomly selected participants and the first consenting children with parental assent were included in the study.

Children with mild ID were recruited through a special school in South Auckland. Information sheets, assent forms and consent forms were sent home with all students with mild ID. All consenting children with parental assent participated in the study. Ethics approval was obtained through the AUT University's Ethics Committee. Overall, thirty five participants were involved comprising 26 children without ID (mean age 11.66 ± 0.77) and nine children with ID (mean age 12.5 ± 2.1). Participant characteristics are presented in Table 3.1.

Table 3.1 Participant characteristics

Participant Characteristics	Children without ID (n=26)	Children with ID (n=9)
Age (years)	11.66±0.77	12.5±2.1
Height (cm)	153.76±9.18	156±18.62
Weight (kg)	50.17±6.36	60.31±14.59
Body Mass Index	21.23±1.90	24.84±5.67
Gender (%)		
Male	46	55
Female	54	45
Ethnicity (%)		
NZ European	61.5	66.7
Maori	15.5	22.2
European Other	23	11.1

STUDY DESIGN

Children **without** Intellectual Disabilities

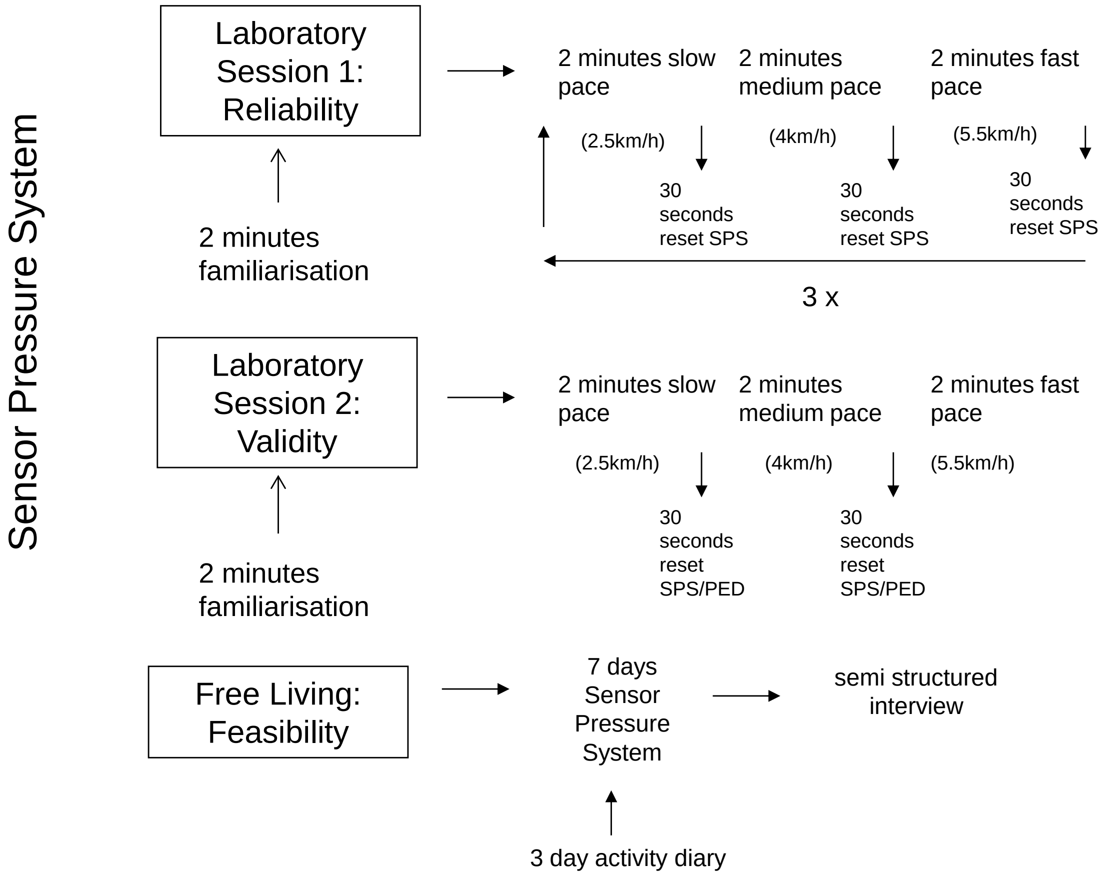

Figure 3.1 The study design for testing the Sensor Pressure System in children without disabilities

Figure 3.1 presents the design of reliability, validity and feasibility testing in children without ID. The SPS was tested for reliability and validity under laboratory conditions in children without ID. Feasibility of the device was examined in free living conditions.

Children **with** Intellectual Disabilities

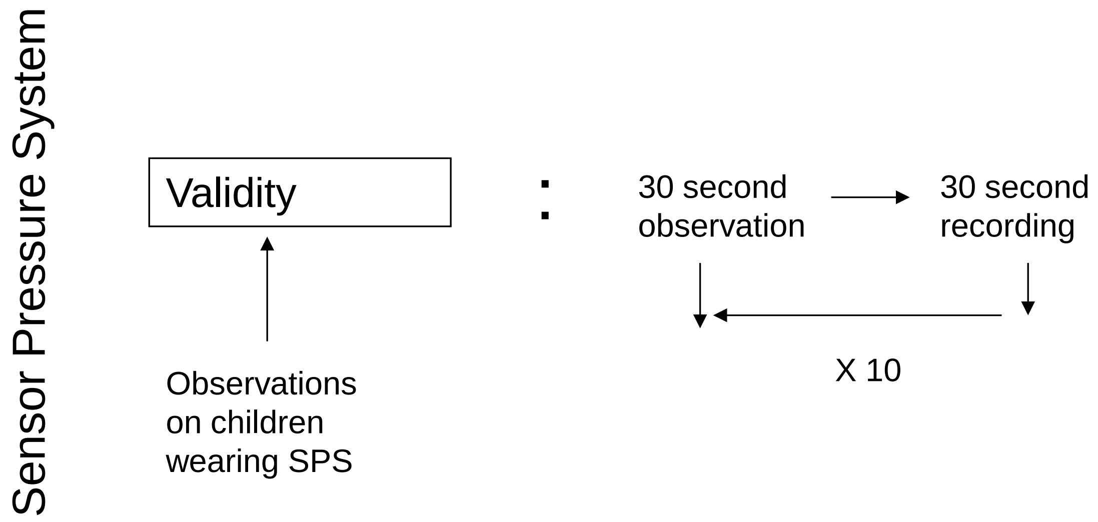

Figure 3.2 The study design for testing the Sensor Pressure System in children with mild intellectual disabilities

The SPS was validated during a PE class in children with ID. Observations were made while children wore the technology during testing. Figure 3.2 details the validity testing design in children with mild ID.

PROTOCOL

Children without Intellectual Disabilities

Reliability Testing: For the first session, ten children wearing their sports shoes reported to the laboratory in the afternoon. Trial order was randomly selected. Children wore the SPS in their left shoe (SPS designed for wearing on left shoe, see tools section) and familiarised themselves with walking on the treadmill. Participants walked normally on the treadmill at a slow (2.5km/h), medium (4km/h) and fast (5.5km/h) pace for two minutes at each speed. Once participants had completed two minutes of walking at the set pace they were instructed to place their feet back on the sides of the treadmill. Children were asked to remain still while data were collected from the SPS to prevent additional steps from being gathered. Directly observed and sensor steps were recorded.

The sensor was then reset. A step was defined at the moment of elevation of the complete foot from the ground. The SPS recorded inaccurate data (see initial sensor testing for detailed explanation) during the first trial and so testing ceased.

After redevelopment (see tools section for a detailed description), the same children reported to the laboratory and the previously described protocol was followed. Compared to direct observation, the SPS was confirmed to be accurately recording steps. Children repeated walking at the slow, medium and fast pace two more times consecutively. The recorded measurements of the SPS were compared within each walking pace.

Validity Testing: Ten children wearing their sports shoes and pants with a waist band reported to the laboratory for validity testing. Trial order was random. Children wore the SPS on their left shoe and Yamax Digiwalker pedometer on top of their left hip. Children familiarised themselves with walking on the treadmill. Participants were asked to walk normally on the treadmill at a slow (2.5km/h), medium (4km/h) and fast (5.5km/h) pace for two minutes at each speed. After walking for two minutes, children returned their feet to either side of the treadmill belt. Children were asked to remain still while data were collected from the SPS to prevent additional steps from being gathered. Directly observed, sensor and pedometer steps were recorded and then the pedometers and sensor were reset. Data from each sensor position (see tools for sensor positioning) were compared to directly observed and pedometer registered steps.

Feasibility Testing: The first ten children who agreed to trial the SPS for seven consecutive days participated. Sensor resistors (see Figure 3.3) were positioned on the sole of children's selected covered shoe. To conceal the sensor resistors, gauze fabric was fixed on top of the sole. The printed circuit board (see Figure 3.3.) was taped on top of the shoe's tongue and the shoe re-laced. Children were asked to complete an activity diary which included; physical activity type, time spent in physical activity, time started and completed physical activity, and the times shoes were worn and removed during the day. Seven days later the SPS and activity diary were collected. At this point a brief, semi-structured interview was conducted with the child and their parent to determine any problems encountered while wearing the device and to hear any suggestions they may have had for improvement (see Appendix M for example interview questions).

Children with Intellectual Disabilities

Four validity testing sessions were conducted with up to three children per session. Prior to a usual, teacher led PE class, children with mild ID were fitted with the SPS on their left shoe. Sensors were set to record total step counts every thirty seconds. Once class commenced one child's steps were directly observed for thirty seconds followed by thirty seconds during which step counts were recorded. When the participant's foot was placed on the ground, a step was tallied on a hand counter. In order to match observations with sensor data, the time batteries were placed in each sensor and the time observations started were noted. The technology was removed upon completion of the PE class. Data from each sensor position were compared to directly observed steps.

TOOLS

Sensor Pressure System

A wearable SPS embeddable in the insole of the left shoe was developed to detect plantar pressure while walking. Two prototype SPSs were manufactured for testing in children without disabilities**.** Early models consisted of three force sensor resistors (FSR 402) (Figure 3.3) which measured the weight of each step.

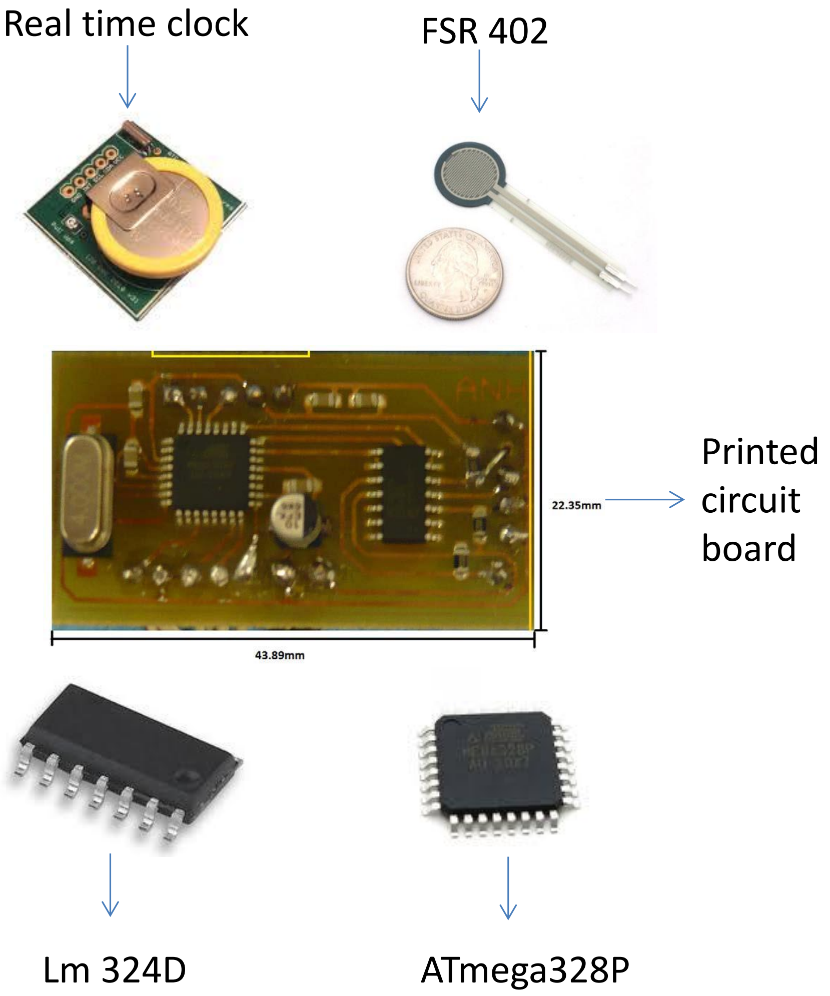

Figure 3.3 Parts of prototype Sensor Pressure System

The sensor resistors were positioned under the inner metatarsal, outer metatarsal and heel. These positions were chosen because they capture the critical part of gait cycle during walking (95). The SPS also comprised a microcontroller chip (ATmega8L) to store data, an op-amp chip (Lm 324D), and a real time clock which were attached to a printed circuit board (Figure 3.3). The printed circuit board was fastened to the side of the participant's shoe throughout laboratory testing (Figure 3.4). During walking, the foot's strike on the sensor resistor formed a voltage pulse to the microcontroller chip which read as one step. The real time clock communicated with the microcontroller chip to read and write current time. Time and total step counts were downloaded to a computer via Bluetooth technology.

Figure 3.4 Prototype Sensor Pressure System attached to the left shoe

Initial sensor testing. During the initial testing session problems were identified with battery life, wire connections and the positioning of sensors. Batteries did not survive the entire testing session due to errors in the electrical charging method, which prevented batteries from fully charging. Modification of the charging circuit solved this issue. However problems were also evident with wire connections. The sensor pad was secured to the sensor board socket and this mechanical contact would occasionally become unstable. During periods of instability, electrical “de-bouncing” occurred whereby the number of steps recorded was greater than the actual steps taken. The SPS was wired and directly soldered to sensor boards to overcome this complication. Additional issues were encountered with inaccurately read step counts when sensors were not positioned correctly on the insole. Further trials found ideal placement to be: inner metatarsal between 11 and 14 of the sole outline depicted in Figure 3.5, outer metatarsal between 9, 10 and 12, and heel between 1 and 2 (Figure 3.5) (96). Two of the remodelled initial pressure sensor systems were used for reliability and validity testing in children without ID.

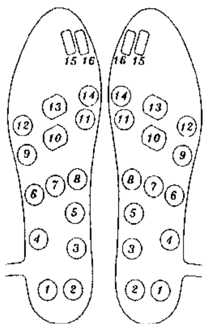

Figure 3.5 Position of inner metatarsal, outer metatarsal and heel sensors (Picture adapted from Perttunen (96))

Final sensor pressure system. After initial laboratory testing was completed the SPS was redesigned to become inconspicuous and record up to seven days of data. Five models were produced for seven day data collection. Two were employed for feasibility testing in children without ID and three sensors were used for validity and feasibility testing in children with ID. The final SPS consisted of a coin cell battery (CR2032), real time clock, microcontroller chip (ATmega328P), force sensor resistor (FSR 402), op-amp chip (MCP6004) and micro SD/SDHC (version 2.0) to store data (Figure 3.6).

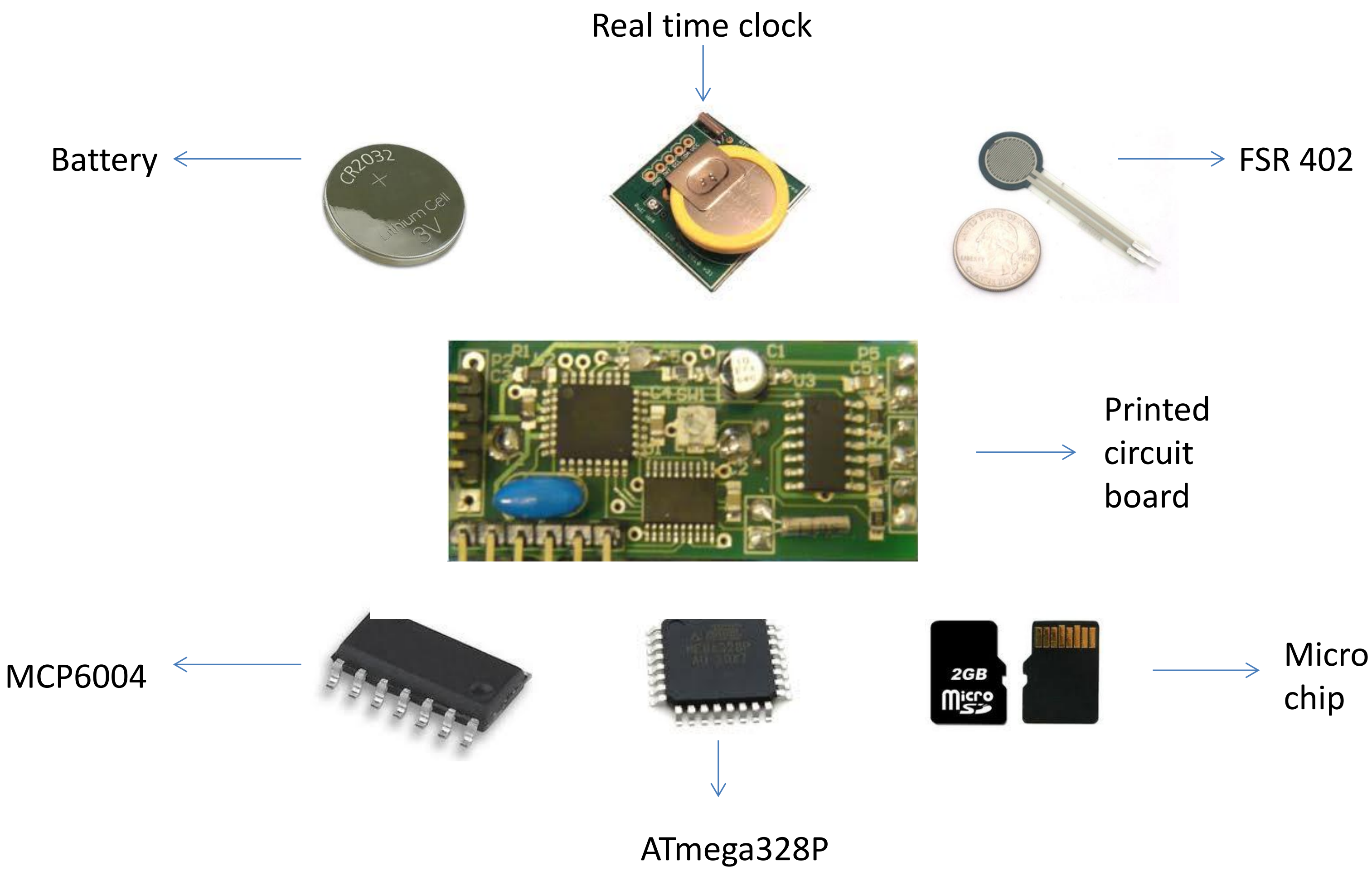

Figure 3.6 Parts of the final Sensor Pressure System

During testing in children without ID, step counts were reset every hour and data displayed as total step counts per hour (24 hour format) for each sensor position (see Appendix K). Consistent with validity testing procedures, step counts of the sensor trialled in children with ID were reset every thirty seconds and data displayed as total step counts per thirty seconds (see Appendix N). The SPS was required to be inconspicuous, therefore the printed circuit board was double layered and reduced to 5.8 centre metres by 2.1 centre metres in dimension. Printed circuit boards were fixed on top of the tongue of a participant's shoe during feasibility testing and concealed by shoe laces (Figure 3.7).

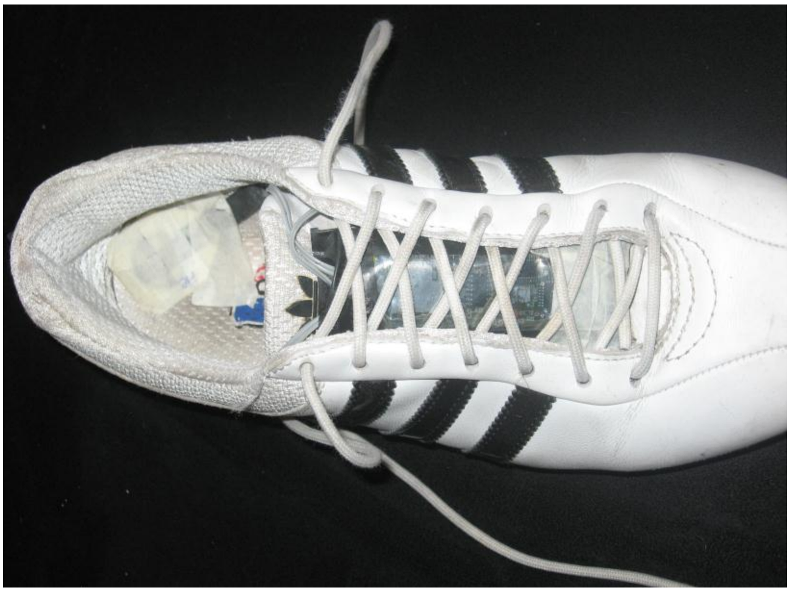

Figure 3.7 Position of the final Sensor Pressure System on shoe

Pedometer

Yamax Digiwalker pedometers measured step counts during validity testing in children without ID. Pedometers were positioned on the left hip of participants during treadmill testing. As pedometers measure step counts of both feet, results were halved to compare to SPS step counts (see Page Four of Section One for justification of pedometer use).

Direct Observation

Step counts of children without ID were directly observed during validity and reliability treadmill testing. Step counts of children with ID were directly observed for thirty seconds followed by a short period to record data. Directly observed steps were tallied on a hand counter (see Page Five of Section One for justification of direct observation).

Qualitative Assessment

Semi-structured interviews were held with parents and children without ID to explore the feasibility of wearing the SPS for seven days. Children and their parents were asked whether children experienced any issues when wearing the sensor on their shoe for seven days, whether there were periods where they were unable to wear their shoe, and if they participated in activities that were not conducive to wearing the modified shoes and finally whether they noticed wearing the sensors (see Appendix M for sample interview questions). Parents were further asked if they had any solutions to the identified problems. Observations were made during validation of the device in children with ID. Children's gait, body shape and their reaction to wearing the sensor were noted (see Page Five of Section One for justification of qualitative assessment).

STATISTICAL ANALYSIS

Data were analysed using SPSS statistical software package version 18.0. All descriptive statistics were presented as means and standard deviations (SD). The intraclass correlation coefficient (ICC) (gold standard for reliability) was used to determine test-retest reliability of the SPS during treadmill trials. Comparisons were made between the three treadmill tests at each different testing pace (slow, medium, and fast) for each sensor resistor position (inner metatarsal, outer metatarsal and heel). An ICC score of 1.0 represents perfect correlation between tests and very high reproducibility of sensor resistor position. A score of 0.0 represents no correlation between each test and very low reproducibility of sensor resistor position. Pearson's correlation (*r)* assessed validity of the SPS during treadmill and PE class trials. Comparisons were made between direct observation and data collected by each sensor position (inner metatarsal, outer metatarsal and heel) at each pace (slow, medium and fast) or during PE class. The properties of Pearson's correlations are similar to ICC, a score of 1.0 displays very high correlation between the two measurement tools and a score of 0.0 displays very low correlation. Since the correlation coefficients only provide information on the degree of association between tests, the change in the mean step counts between trials for each of the three testing paces at each sensor position was determined. Absolute percentage error comparisons were also calculated. The absolute difference between each sensor position during each different condition (fast pace, medium pace, slow pace and classroom) and criterion measure (direct observation) was examined. Sensor measured steps were divided by the criterion steps and multiplied by 100 to provide absolute percentages. A content analysis was undertaken for semi-structured interviews with data coded and categorised for common statements. Observations on children with ID are presented individually. Interview data and observations were described qualitatively.

CHAPTER 4: RESULTS

The following section is organised by reliability, validity and feasibility results in children without ID and followed by results in children with ID. All means and standard deviations are rounded to significant figures. Correlations, confidence limits and percentage errors are rounded to two decimal places.

Twenty six children without ID participated. Of the 26 children, 10 children completed reliability testing in the laboratory, 10 children completed validity testing in the laboratory and 10 children wore the SPS for seven full days in free living conditions (see Figure 4.1). Nine children with mild ID participated in validity testing during a PE class. Participant characteristics are presented in Table 3.1.

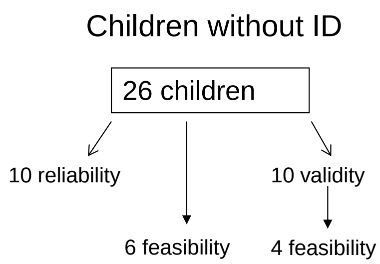

Figure 4.1 Numbers of children without intellectual disabilities participating in testing

Children without Intellectual Disabilities

Reliability: In comparison to heel and outer metatarsal positions, the inner metatarsal position displayed higher reproducibility (ICC = 0.86-0.95, see Table 4.1).

Table 4.1 The intraclass correlation coefficient and confidence intervals of the Sensor Pressure System placed at three different positions for measuring step counts at slow, moderate and fast treadmill speeds in children without intellectual disabilities

Speed (km/h)	ICC	Confidence Interval	
		Lower	Upper
	Heel		
2.5	0.65	0.29	0.88
4.0	0.54	0.15	0.84
5.5	0.50	0.11	0.82
	Inner Metatarsal		
2.5	0.95	0.86	0.99
4.0	0.89	0.71	0.97
5.5	0.86	0.65	0.96
	Outer Metatarsal		
2.5	0.65	0.30	0.89
4.0	0.54	0.15	0.84
5.5	0.51	0.12	0.82

ICC: Intraclass Correlation Coefficient

Heel and outer metatarsal positions demonstrated similar moderate reliability (ICC=0.50-0.65). Overall, sensors were more reliable during slow speeds (ICC = 0.65-0.95). The smallest change in the mean was detected at the inner metatarsal position between Trial 3-2 during the slow speed (0.3 steps). The largest change in the mean was observed between Trial 3-1 for the outer metatarsal position at the medium speed (5.6 steps). The ICC and confidence interval of heel, inner metatarsal and outer metatarsal positions of the SPS when worn by children without ID for three consecutive bouts of walking on a treadmill at a fast, medium and slow pace are shown in Table 4.1.

Table 4.2 presents the mean, standard deviation and mean differences with the qualitative descriptor between each trial for the heel, inner metatarsal and outer metatarsal positions of the SPS. Testing was conducted by children without ID for three consecutive bouts of walking on a treadmill at a fast, medium and slow pace.

Table 4.2 The mean (± standard deviation) and mean differences between each trial with the qualitative descriptor of the Sensor Pressure System placed at three different positions for measuring step counts at slow, moderate and fast treadmill speeds in children without intellectual disabilities

Speed (km/h)	Mean ± SD (step counts)	Mean differences and qualitative descriptors					
		2-1		3-2		3-1	
	Heel						
2.5	78 ± 11	-5.3±0.43	Possibly	1.1±0.10	Unlikely	-4.2±0.51	Possibly
4.0	99 ± 15	1.7±0.08	Unlikely	2.6±0.24	Unlikely	4.3±0.57	Possibly
5.5	112 ± 20	-5.60±0.22	Unlikely	8.30±0.44	Possibly	2.70±0.28	Unlikely
	Inner metatarsal						
2.5	70±27	-2.90±0.11	Unlikely	0.30±0.01	Very Unlikely	-2.60±0.10	Unlikely
4.0	89±33	3.3±0.09	Unlikely	3.7±0.11	Unlikely	7.0±0.21	Unlikely
5.5	100±41	4.2±0.1	Unlikely	7.0±0.03	Very Unlikely	2.80±0.08	Unlikely
	Outer metatarsal						
2.5	77 ± 10	-5.5±0.49	Possibly	1.7±0.18	Unlikely	-3.8±0.44	Possibly
4.0	98 ± 15	1.4±0.07	Unlikely	4.2±0.39	Possibly	5.6±0.88	Likely
5.5	110 ± 20	-5.9±0.23	Unlikely	9.4±0.49	Possibly	3.5±0.36	Possibly

SD: Standard Deviation; Possibly: possible that the effect was due to chance; Unlikely: unlikely that the effect was due to chance; Very unlikely: very unlikely that the effect was due to chance; Likely: likely that the effect was due to chance.

Validity: Significant Pearson's correlations were observed between inner and outer metatarsal positions and directly observed steps at all speeds (*r* =0.84-0.96). At slow and medium speeds, correlations between the heel position and directly observed steps were low (*r* = 0.09 and 0.08 respectively). However, high Pearson's correlations between the heel position and directly observed steps were identified at fast speeds. In general, the SPS showed the highest precision at fast speeds. Overall the new technology captured ± 12 % of directly observed steps. All SPS positions during all speeds displayed higher Pearson's correlations between directly observed steps compared to pedometers. Pedometers underestimated more directly observed step counts more than the SPS did (41.5% and 12% respectively). During fast speeds the SPS overestimated directly observed steps by 0.1-1.1%. Pedometers did not overestimate step counts. Table 4.3 shows the mean and standard deviation of heel, inner metatarsal and outer metatarsal positions of the SPS, directly observed steps (criterion measure) and steps registered by pedometers when worn by children without ID during validity testing.

Table 4.3 The mean (± standard deviation) of step counts from direct observation, Yamax Digiwalker pedometer and the Sensor Pressure System placed at three different positions at slow, moderate and fast treadmill speeds in children without intellectual disabilities

	Direct Observation	Yamax Digiwalker	Sensor Pressure System		
	Step counts				
Speed (km/h)			Heel	Inner metatarsal	Outer metatarsal
2.5	95 ± 10	55 ± 30	83 ± 30	93± 11	93 ± 10
4.0	115 ± 9	106 ± 20	105 ± 32	113 ± 12	113 ± 12
5.5	140 ± 42	113 ± 32	142 ± 48	141 ± 45	141 ± 45

In Table 4.4 the percentage error and Pearson's correlations between the three positions of the SPS and the criterion measure are displayed.

Table 4.4 Pearson's correlation and percentage error of the Sensor Pressure System at three different positions against direct observation for measuring step counts at slow, moderate and fast treadmill speeds in children without intellectual disabilities

Speed (km/h)	*R*	Percentage error (%)
	Heel	
2.5	0.09	-12
4.0	0.08	-9.2
5.5	0.90*	+1.1
	Inner metatarsal	
2.5	0.95*	-1.9
4.0	0.84*	-2
5.5	0.95*	+0.1
	Outer metatarsal	
2.5	0.96*	-2.2
4.0	0.84*	-2
5.5	0.95*	+0.1

R: Pearson's correlation; *: Significant correlation ($p<0.05$)

Pearson's correlations and the percentage error between directly observed steps and the Yamax Digiwalker pedometer are shown in Table 4.5.

Table 4.5 Pearson's correlation and percentage error of the Yamax Digiwalker pedometer against direct observation for measuring step counts at slow, moderate and fast treadmill speeds in children without intellectual disabilities

Speed (km/h)	*R*	Percentage error (%)
2.5	-0.07	-41.5
4.0	0.76*	-7.6
5.5	-0.48	-19.2

R: Pearson's correlation; PED: pedometer; *: Significant correlation ($p<0.05$)

Feasibility: Quantitative data were presented as total step counts read by each SPS position per hour (e.g. 19/1/12:9:0:0 Heel=4 Outside=2 Inside=4). Each position recorded different step counts when children wore the device for seven days (see Appendix K). Heel sensors often broke before the seven day collection was complete. Batteries tended to last between four and seven days depending on how often children wore the device. Children who removed their shoes the least, had the shortest SPS battery life. The more the SPS was trialled, the less data it would collect from the next participant. No data were collected from the last three children who wore the SPS for seven days. All activity diaries were returned incomplete therefore were not included in data analysis.

Semi-structured interview data were analysed in relation to the issues encountered by children while wearing the SPS for seven days. Table 4.6 presents the categories of participants' perceptions on the utility of the SPS for measuring step counts over seven days.

Table 4.6 Perceptions on utility of the Sensor Pressure System for measuring children's step counts over seven days: participant quotes

Categories	Quotes
School rules	"…have to wear their school shoes during the day at school…" (parent) "…teachers kept on asking me about my shoes…it was annoying…I had to get a note written…" (child) "…teachers really liked it (that I was participating in a research project)…" (child)
Household rules	"…they can't wear shoes inside…" (parent) "…have to take his shoes off in the house…" (parent) "…actively plays when he is inside" (parent)
Weather	"…so hot they went inside to play…" (parent) "…spent the afternoon at the beach…obviously had to take their shoes off…" (parent)
Activity type	"I was skateboarding…shoe (with sensor) was on the skateboard…other one pushing (foot)…" (child) "When I was scootering (the shoe with sensor stayed on the scooter)…" (child) "… (I) had surf (lifesaving) all day in the weekend…" (child)
Shoe type	"…got new shoes and wanted to wear them…" (child) "…too hot wearing them (closed shoes) and so took them off…" (parent)

Parents and children commented on certain school rules which prevented the same type of shoe from being worn for seven days. One child who was required to wear uniform shoes and who was provided with an exemption note felt inconvenienced at having to constantly produce the note when spoken to by teachers for wearing incorrect shoes. Conversely, the other children who wore non-uniform shoes indicated that teachers were supportive and encouraged their participation in a research project. All children preferred to wear non-uniform shoes and were excited with being exempt from wearing school uniform shoes.

Some parents discussed their household rules which limited the measurement time of the SPS. Many participants' households required shoes to be removed when inside which meant children's step counts were not captured while inside. Some parents did not feel this was a problem as their child/ren did not perform much physical activity while inside. However, other parents believed their child/ren were still physically active inside and the device would underestimate their daily activity.

Weather was another limiting factor, mentioned by parents and children, to wearing the SPS. The current study was conducted during summer and many participants discussed going to the beach where children would take their shoes off to play and swim. In addition, some parents mentioned how their children went inside to play in the afternoon during high temperatures. In this case, while children still actively played inside, they were required to take their shoes off which prevented SPS capturing their afternoon's activity.

The type of shoe also dictated the total amount of data collected by shoe sensors. Children discussed removing their closed shoes when temperatures were too high. Parents recommended sensors which were suitable for wearing in sandals in order for children to comfortably wear them during summer. One child was given new shoes during the study and with the excitement of new shoes, chose to wear those rather than their shoes with the SPS.

Having regard to the limitations around weather, school and household rules, parents and children believed that modifying the SPS so it was easily transferable to other shoes and wearable in open shoes would increase data collection time. One parent mentioned that certain types of sports shoes had removable soles which could potentially allow the device to be embedded in the sole. Although there were no recommendations for developing the SPS to suit open shoes, parents felt this was the most appropriate method as children could then wear the device throughout the entire year.

Most children recognised that some physical activities would not be captured by the SPS. Skateboarding and scootering were identified by children who were right handed and therefore whose right foot was pushing along the ground while their left foot was stationary and not capturing the physical activity. In addition, one child discussed their involvement in surf lifesaving over the weekend of their testing. During the day they were running on the sand and swimming in the sea and were unable to wear their shoes which meant the device did not measure this physical activity. Parents also voiced the same concerns regarding the SPS's ability to capture bicycling. Laboratory trials confirmed these concerns as the pressure on the downward cycle when pedalling was not great enough for the sensors to register this movement as a step.

Children with Intellectual Disabilities

Validity: The means and standard deviations of each SPS position and directly observed step counts during a teacher run PE lesson are displayed in Table 4.7.

Table 4.7 The mean (± standard deviation) and Pearson's correlations of the Sensor Pressure System in three different positions against direct observation for measuring step counts in children with intellectual disabilities during a teacher run Physical Education class

	Mean ±SD	*R*	Percentage error (%)
Direct observation	163 ± 30		
Position of sensor			
Heel	120 ± 85	-0.27	-26
Inner metatarsal	150±83	0.13	-8
Outer metatarsal	118± 84	-0.37	-28

PE: physical education; SD: standard deviation; *r*: Pearson's correlation

In addition, the Pearson's correlation and percentage error between each SPS position and directly observed step counts are represented in Table 4.7. Low Pearson's correlations were observed between inner metatarsal sensors and directly observed steps (r =0.13). Outer and heel sensor positions displayed inverse Pearson's correlations (-0.37 and -0.27 respectively). The SPS underestimated directly observed steps by 8 to 28%. The inner metatarsal position was the most accurate at recording step counts in children with ID.

Feasibility: To assess the long term feasibility of wearing the devices it was initially proposed that ten children aged between 10-12 years and living with ID would wear the SPS for seven days. Shortly after school had commenced for the morning two children with ID were fitted with the device in their left shoe to wear for seven days. A teacher aide was present during the fitting to ensure the children were comfortable with the procedures. One child wore sports shoes with plastic insoles and Velcro straps, the other child wore rubber crocs. Sensors were positioned on the sole of the children's left shoe. The circuit board was placed on the tongue of the sports shoe and concealed by Velcro straps when fastened. The circuit board was taped to the top of the crocs and concealed using black masking tape which matched the shoe colour.

Children were provided with a three day activity diary and their parents/caregivers were asked to record when their child removed their shoes at night, put them on in the morning and when they removed their shoe during the day. In addition, parents/caregivers were asked, when possible, to record the time, type and intensity of any physical activity their child undertook during the day.

In the morning of the second day children arrived at school with the SPS damaged. Discussion with the teacher aide revealed that the heel sensor placed on the crocs shoe "came unstuck" and one of the child's peers removed it from the shoe. The child wearing sports shoes arrived at school with sensor positions still intact in the sole of the shoe, however the circuit board was removed. The parents of the child wearing sports shoes spoke limited English and the teacher aide believed the parents had observed the circuit board and, without understanding, removed it from the tongue of the shoe.

Due to the previously described issues it was not yet feasible to have children with ID wearing the SPS for up to seven days. In order to further develop the SPS to suit the special needs of children with ID it was necessary to better understand these children's physical activity behaviour. The SPS was validated in children with ID during physical education class. Table 4.8 presents observations from each child.

Table 4.8 Observations by children with intellectual disabilities while wearing the Sensor Pressure System during a Physical Education class

Child	Observations
Child one	A small young child who only weighed 45kg wore black school shoes with laces. Shuffled when walked, picked feet up but did not place back on the ground with enough force for sensors to register steps. The SPS did not register any of this child's steps.
Child two	An overweight young child wore slip on covered shoes which had no laces. Shuffled when walked, picked feet up but placed back on ground with enough force for sensors to register steps. On this child, the SPS over estimated steps by 1.8% to 4.3%.
Child three	A slim teenager who was of average height and wore Roman sandals, pointed toes slightly inwards when walking but appeared to walk normally with heel placement first and then finishing on the ball of the foot. On this child, the SPS over estimated steps by 13 to 14.4%.
Child four	A young child of average build who wore Roman sandals, walked carefully as though was nervous to put feet on the ground, often had to have a teacher aides assistance to move around the room as would not walk over to another activity on their own. When placing their feet on the ground the child would place their whole foot at once with limited plantar and dorsiflexion to their steps. The heel sensor position did not register any steps, the inner sensor position overestimated by 12% and outer sensor position underestimated by 88%.
Child five	A tall child, of average weight, who wore Roman sandals, took long steps when walking which shortened in length when running and plantar flexion and dorsiflexion seemed slightly smaller than normal. On this child, the SPS overestimated steps by 2-8%.
Child six	A very tall, slim teenager who wore black lace up school shoes, took very long strides when running and walking and appeared to look awkward when running and walking as though their legs were too long for their body. On this teenager the SPS overestimated steps by 62- 95%.

Child seven	An average height teenager who was solidly built and wore black school shoes with no laces, walked with a slight swagger and a small shuffle. On this teenager the SPS underestimated by 65.3 to 67.6%.
Child eight	A teenager of average height and weight who wore black lace up school shoes, dragged feet slightly when walking but when running, picked feet higher up off the ground. On this teenager the heel and outer sensor positions underestimated by 44-75% and the inner sensor position overestimated by 18%.
Child nine	A thin average height teenager who wore black lace up school shoes, dragged right leg along the ground when walking and would "gallop" when running as ran with left foot, and dragged right foot along the ground behind. Tired easily and would start shuffling with left foot. Inner and outer sensors underestimated steps by 18% while heel sensor overestimated steps by 11%.

Only one young girl reacted negatively to having the SPS attached to her shoe. She could see the tape holding the circuit boards in place and mentioned how there was "…something on my shoe". It was not an issue for her to wear the shoe, however during her PE class she tried to push the circuit board off the tongue of her shoe with her right foot despite being requested not to by the teacher. All other children did not notice the SPS in their left shoes once their PE class commenced.

Many of the children with ID had gait limitations which may have prevented accurate data being captured. Some children with ID shuffled or only ran on the balls of their feet or on their outer metatarsals. The SPS did not register the movements as step counts of one of the children who shuffled. The child whose movements were not registered was the lightest participant.

CHAPTER 5: DISCUSSION

This is the first study to develop and assess a shoe based Sensor Pressure System (SPS) for measuring daily step counts in children with and without intellectual disabilities (ID). The SPS accurately captured step counts in children without ID and displayed acceptable reproducibility. In children with ID the SPS showed low validity in measuring step counts. The prototype needs further development to better characterise daily physical activity in children with ID.

The SPS concept was based on a shoe mounted pedometer developed by Hoodless and colleagues (97). The Hoodless device consisted of a transducer, circuitry and rechargeable battery embedded in the heel of participants' shoes (97). In their study, 10 young healthy males validated shoe-pedometers against directly observed steps and hip-pedometers. Seventeen elderly participants with chronic heart failure and 10 age-matched healthy participants wore shoe and hip-pedometers for seven days. Analysis revealed that shoe pedometers were more accurate measures of step counts than hip-pedometers (97). In addition, the shoe-pedometers recorded higher daily step counts than hip worn devices. A key difference between the SPS and Hoodless (97) technology was that the Hoodless device detected motion compared to applied weight as in the current study.

More recently, shoe based pressure sensors have been created for short durations of gait analysis (98, 99). Saito and colleagues (99) manufactured a shoe insole with seven pressure-sensitive sensors to assess plantar pressure in the elderly during daily living for fall prevention. The device accurately recorded plantar pressure of one healthy young adult and two elderly subjects over seven metres (99). An important difference between the current study and Saito's (99) device was that the SPS measured daily step counts while Saito's technology was employed to measure changes in plantar pressure. A limiting factor to Saito's (99) work was that the device was developed for daily living assessment, however was only validated over seven metres. As it was intended that the SPS would measure step counts of children, the feasibility of children wearing the technology over seven days was investigated.

Bamberg et al. (98) created a wireless wearable gait analysis system that included force sensors. The gait analysis system was trialled by sixteen adults, half with a Parkinson gait and half with a healthy gait. The device was capable of detecting heel-strike and toe-off, and estimating foot orientation and position (98). Similar to Saito and colleagues (99), Bamberg et al. (98) developed the device for adult gait analysis in free living conditions, but testing was conducted in the laboratory (98, 99). The current study developed the SPS for measuring daily step counts and was trialled in free living conditions.

Sazonov and associates (95) produced foot-wear based technology consisting of an accelerometer and pressure sensors to measure the energy expenditure of participants (95). The technology was validated in 16 adults ranging from lean to obese, smokers to non-smokers, and sedentary to active. Participants performed a range of postures/activities, including sitting, standing, jogging, walking and cycling, while wearing a portable metabolic cart and the foot-wear based technology. The device accurately measured energy expenditure in adults' postural and common daily activities. In addition, the foot-wear technology was accurate in lean and obese individuals (100). When subsequently the device was subsequently trialled with people suffering from a stroke, the device provided valid information on sitting, walking and standing postures (101).

Sazonov and colleagues (95) utilised their pressure sensor to measure energy expenditure; the SPS in the current study assessed daily step counts. Step counts are an understandable and easily quantifiable measure of physical activity (43). There are international guidelines which recommend boys engage in a minimum 15, 000 steps daily and girls engage in 12, 000 steps daily (102). These international guidelines facilitate physical activity comparisons globally.

This is the first study to evaluate the change in the means between two laboratory trials of a step counter tool in typically developing children. The difference between the means during each pace (fast, medium and slow) at the inner metatarsal position was the smallest which suggested that at this position there was the least likely measurement error compared to the other two positions. The largest change in the means at each pace was detected at the outer metatarsal position, therefore data found at this position contained the largest measurement error. The variation in measurement error at each sensor position could be due to gait differences. In a typical gait there are four events which complete the gait cycle. The first being foot strike, followed by opposite toe-off, opposite foot strike and the toe-off. It is expected that the heel will make contact with the ground first. However, in pathological gait (e.g. toe walkers), other areas of the foot may contact first (103) which may influence data collection. It is also possible that areas of the foot do not make contact with the ground in every gait cycle which could affect the change in means between tests. The effects of gait differences and other possible influences on test-retest reliability of each SPS position need to be further examined.

Test-retest reliability of the SPS was moderate to high. Like the results of the Digiwalker pedometer **interinstrument** reliability studies, the inner metatarsal position displayed the highest reproducibility during slow speeds (ICC=0.95). The ICC of pedometers during two occasions of walking, fast walking, and running ranged from 0.51 to 0.92 (90). In addition, the correlations were lower during running compared with walking and fast walking (90). However, testing in the current study was for short durations. The SPS is intended for daily measurement which means testing needs to be conducted for longer periods of time.

No studies have examined test-retest reliability of pedometers or other subjective physical activity measures in children with ID. Pitetti et al. (28) evaluated the within subject reproducibility of heart rate monitoring in 15 children with mild ID on three non-consecutive days. The resting heart rate protocol used was similar to determining resting heart rate in children without ID. Measurements were taken upon arriving at school, within 30-60 minutes of waking and without prior exercise. Heart rate monitors were fitted and children reclined on bean bags while listening to a storybook for 30 minutes. The ICC for resting heart rate was 0.99 (28). However, participants refusing to be instrumented was a limitation identified in the Pitetti study (28). In the current study participants did not refuse to wear the SPS in their shoe.

A small number of children with ID were sampled in this current study. It is recommended that following further development of the SPS, more trials are undertaken with a larger sample of children. In addition, participants in Pitetti (28) and the current study had mild ID. It may be that refusal rates are higher in children with more severe forms of ID. The SPS needs to be trialled in children with moderate to high ID to determine children's tolerance of the device.

Overall, sensor positions were most reliable at slow speeds in typically developing children, which is consistent with findings in studies using the Digiwalker pedometer (44, 90). However, in the current study, ICCs differed between each sensor position at the same speed. All sensor positions were developed using identical materials and procedures, therefore a plausible explanation for the large variance was the placement of the device on the insole. Sensors were positioned under the inner metatarsal, outer metatarsal and heel, the parts of the gait cycle considered critical in capturing participants' steps (95). As the participants had varying shoe sizes, the SPS was individually fixed onto each participant's insole. This may have resulted in slightly different positioning with each fitting. The SPS should be developed into a shoe insert to ensure correct positioning regardless of shoe size.

In this study inner and outer metatarsal positions accurately measured step counts. Compared with directly observed step counts, inner and outer metatarsal positions were more accurate than pedometers in measuring step counts. In addition, the Pearson's correlations identified in the present study were higher than correlations obtained by researchers validating pedometers (90). In laboratory and field conditions among 3 to 11 year old typically developing children correlations from 0.59 to 0.90 were identified between the Digiwalker pedometer and directly observed steps (90). The higher correlations in this study suggest that the SPS is a more accurate measure of children's step counts than pedometers. However, validity testing of the SPS was conducted in the laboratory and results need to be confirmed in free living conditions.

Consistent with pedometers, all SPS positions were more accurate at fast speeds compared with medium and slow speeds (44). It is plausible that factors such as gait differences in children may impact the SPS validity. Step counts of children who were toe walkers (as previously described) may not have been accurately captured by the SPS heel position as the heel was not utilised (103). Further investigation into the low validity values observed by heel sensors needs to be conducted.

Some inverse correlations were identified between the SPS and direct observation. The inverse correlations indicated that the SPS recorded greater steps than directly observed steps (the criterion measure). Percentage errors were also calculated to compare SPS measured step counts with criterion findings. The heel position and outer metatarsal position underestimated more steps in children with ID compared to Pitetti's (49) pedometer findings. In children with ID, pedometers underestimated step counts by an average of 14% (49). However the inner metatarsal position was more accurate than pedometers in children with ID.

No other work has validated the same measure of physical activity and compared it to children with and without ID. The SPS displayed low validity in children with ID and high validity in children without ID. The device was validated under laboratory conditions in children without ID and in a PE class setting in children with ID. Walking speeds were controlled on a treadmill in the laboratory while activities and intensities were varied over the course of observations during the PE class. It is common for the gait of many children with ID to be different to that of children without ID. Some children with ID ran on the ball, outer, or inner part of their feet and, when tired, dragged their feet along the ground. A recent review identified differences in spatiotemporal characteristics of gait in children with Down's Syndrome compared to typically developing children. In general, children with Down's Syndrome were found to have slower walking speed, higher rate of steps per minute, shorter step length, larger step width and longer double support time (period during gait cycle which both feet are on the ground) (104). Further investigation is required to determine the influence of these gait differences on the use of SPS.

In addition, the step counts of a small child with ID who shuffled were not measured by the SPS, while the steps of a larger child with ID who shuffled were captured. The SPS may not have captured the steps of the smaller child as their weight may not have been at a magnitude for the device to detect pressure changes. In the current study, a step was defined as elevation of the complete foot from the ground. Using this definition of a step, shuffling should not be included in data collection. However, the purpose of the SPS was to objectively measure physical activity in children with ID. Physical activity is any bodily movements involving skeletal muscles which results in energy expenditure (1). Shuffling produced energy expenditure and was included in direct observations. It should therefore be captured by the SPS. The SPS needs to be validated in a range of different gait cycles and anthropometric characteristics.

A key limitation with current objective measures of physical activity was refusal of children with ID to be instrumented. The SPS in the present study was developed to be inconspicuous; however, on open shoes or shoes without a tongue, the printed circuit board was noticeable. One child noticed the printed circuit board attached to their shoe and questioned the reason it was there. In addition, during the PE lesson, that child attempted to push the printed circuit board off the shoe with their other foot. However, no children refused to be instrumented as the device was not in direct contact with their bodies.

Children with ID may not understand the necessity for data collection. When the SPS was trialled on children with ID for seven days the heel sensor was broken by one child and another detached the printed circuit board. It would appear that the SPS was broken due to a lack of understanding of the importance and necessity for measurement. In comparison, children without ID understood the reasons for measurement and most children attempted to wear their shoes as long as possible. The way in which children with ID touched and tried to remove the device reinforced the necessity for the SPS to be inconspicuous, to fit entirely within children's shoes, without any apparatus on the outer shoe. To this end the SPS needs to be more compact.

No other studies have trialled a measurement device requiring children to wear the same item of clothing for seven days. In the current thesis, it was not feasible for children without ID to wear the same shoe for seven days. There were many periods during the day when no data were collected by the SPS indicating that participants removed their shoes regularly. Qualitative data confirmed these findings as children discussed taking their shoes off during high summer temperatures, when inside and for certain activities. Hoodless and colleagues (97) trialled their shoe pedometer in elderly participants over seven days and did not discuss any issues with participants wearing the same shoes for the testing duration. However, there was no indication during which season testing was undertaken and the subjects in that study were elderly compared to children in the current thesis. To overcome any seasonal limitations, the SPS should be manufactured as part of an insole which can be inserted into a closed shoe or an open sandal. An insole would also enable children to wear different shoes during data collection, as the device could be easily transferred between shoes. Furthermore, as previously discussed, it is important for the SPS to be inconspicuous in both open and closed shoes. Developing sensors into an insole may eliminate children touching and breaking sensors.

The current batteries were not appropriate for seven day data collection. Only four to five days of data were collected by children who wore their shoes during the full seven days. Replacing batteries during testing is costly and adds to participant burden and so other avenues need to be explored. Shenck and Paradiso (105) developed a piezoelectric insole which can be inserted in the heel of a shoe to absorb excess energy produced by walking and convert it to electrical energy. However, the piezoelectric insole has a circuit board attached to the outside of the shoe's heel (105). The final SPS prototype developed in the current project was inconspicuous. In its current state the piezoelectric insole may be too cumbersome and will prevent the SPS from being inconspicuous if added to the device. Nonetheless, the concept of collecting excess energy and converting it to electrical energy should be explored for powering the SPS.

Printed circuit boards used in the present technology may also have limited use. Near the end of feasibility testing in children without ID, one SPS had been worn by four or more children. When the last child wore the device, no data were collected. A plausible explanation may be that printed circuit boards were damaged through general use and have limited data collection life. The circuit boards were encased in a thin plastic case which did not offer much protection. The printed circuit boards in any future SPS need greater surround protection to ensure maximal data collection.

As the SPS was placed on the children's left shoe, activities requiring movement of the right foot, such as skateboarding and scootering, were not captured. In addition, the technology did not register steps while cycling. It would appear the force applied during pedalling was not great enough to register as a step. While skateboarding, cycling and scootering are not common activities amongst children with ID (38, 67), the SPS may be used to measure physical activity in all children and so these activities should be captured. Further trials need to be conducted to identify the correct force to capture both cycling and walking pressure, while eliminating the possibility of capturing fidgeting and foot tapping. For future testing, one SPS in each shoe may be required to gain more accurate results.

Other limitations noted by parents and children without ID were household and school rules. Many households did not allow shoes to be worn inside. As one parent noted, their child played inside with a friend one afternoon. While the children's play was active, it was not captured, as the children had removed their shoes. In addition, many schools have uniform shoes which children are required to wear. In the current study, children were exempt and able to wear non-uniform shoes for the week. However, in large studies exemption from wearing uniform shoes may not be practicable and would depend on the willingness of the school to accommodate the needs of the study. As previously described, developing the SPS into an insole would overcome the issue of school rules. However, the insole concept would depend on children's ability to remember and understand the importance of moving the SPS to the next shoe.

CONCLUSION

The Sensor Pressure System is a valid and reliable measure of step counts in children without intellectual disabilities. Due to its relatively inconspicuous nature, the device has potential for use in children with ID. However, further development is required for the Sensor Pressure System to better capture steps counts in children with ID. It is recommended that development of the next version should include:

- Insoles that can fit in different shoes sizes;
- A completely inconspicuous device;
- A rechargeable battery or other mechanism to power the sensor;
- Positioning of the force sensors on the insole; and
- Calibration to capture cycling

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APPENDICES

Appendix A: Principal Information Sheet for Typically developing children

Principal's Information Sheet

DATE INFORMATION SHEET PRODUCED: 29TH MARCH 2011

PROJECT TITLE
A novel pressure sensor to objectively measure physical activity in children

AN INVITATION

Hello my name is Amy Curtis, I am a Master's candidate at AUT University, and I would like your school to take part in my **Pressure Sensor** research project. Thank you for considering joining this research project. Please read the following information sheet carefully before deciding to take part. If you have any questions please ask.

Amy Curtis
School of Sport and Recreation,
Faculty of Health Sciences,
Akoranga Campus,
Auckland University of Technology,
Private Bag 92006, Auckland 1020.
Phone 921 9999 extension 7848
Email: acurtis@aut.ac.nz

The purpose of the **Pressure Sensor** project is to develop a valid and reliable shoe-mounted sensor for the objective measurement of physical activity in children.

I will be testing the validity, reliability and feasibility of pressure sensors to measure daily step counts and intensity in children. During one afternoon children will be required to attend validity and reliability testing at AUT. Children will wear sensors and pedometers while walking on the treadmill at different speeds. To test feasibility, children will also be provided with sensors to wear for one week in their favourite shoe and will also wear pedometers during that week. Children will be required to fill out activity logs twice daily to capture their physical activity levels, for at least three days they are wearing the sensor.

I will require access to your school to recruit children onto the project. I am going to be randomly selecting children to participate so would need access to your Year 7&8 roll. I will need to speak with the randomly selected children to explain the project and provide the children with information and invitations to participate. A child may not join in this study without the approval of a parent or legal guardian and the consent of the child. Your school is free to withdraw consent and stop at any time without changing your present and / or future involvement with AUT University. Your consent to allow the **Pressure Sensor** Project to access your school will be indicated by signing the consent form provided.

WHAT IS THE PURPOSE OF THIS RESEARCH?

The purpose of this research is to develop a cost-effective, valid and reliable, objective measure of physical activity. Subjective measures of physical activity, such as self-report questionnaires and time use diaries, are a cheap measure and can provide activity settings and type of physical activities, however, can be unreliable as they are subject to self-reporting bias, memory, understanding and peer pressure. Objective measures such as Direct Observation, Accelerometers and Pedometer, are often more reliable. However, direct observation is time consuming, accelerometers are expensive and do not provide setting and type of physical activity and pedometers can be subject to participant tampering and only give an indication of daily step count. Furthermore, these objective measures may alter usual behaviours as participants are aware that they are being measured.

As children's most common physical activity is walking, a sensor that is placed in the sole of the shoe that can detect steps might be a way to objectively measure daily activity in all children. The proposed shoe sensor will not be subject to participant tampering as it will detect the amplitude and duration of force at a certain level, rather than movements, therefore a step bearing the child's weight will need to be taken in order for it to register in the sensor. Additionally, children can easily forget they are being measured as the sensor will be placed in their shoe and will be less likely to alter usual behaviours, potentially making it a more reliable measure of physical activity than pedometers.

HOW WAS I CHOSEN FOR THIS INVITATION?

Your primary school was randomly selected and invited to participate in the **Pressure Sensor** project.

The **Pressure Sensor** project is inviting the first ten consenting children aged ten to twelve years to join the project.

WHAT WILL HAPPEN IN THIS RESEARCH?

Parents and whanau are invited to be present during treadmill testing, and at the time pressure sensors and diaries are given to their child.

The validity and reliability testing phase will take place during one afternoon in the start of Term 2. The first nine consenting children will be required to wear a pedometer and pressure sensor while walking on the treadmill at slow, medium and fast pace. During the time children are walking step counts will also be observed.

The feasibility testing phase will take place over 7 days in the end of Term 3. Children will be fitted with a pressure sensor in the sole of their favourite shoe and requested to wear this shoe upon waking during the 7 days. Children will also be provided an activity diary to log their activity twice daily for a minimum of 3 days (2 weekdays and 1 weekend) and pedometers to wear for the 7 days. At the end of 7 days children will be asked some simple questions on how they found wearing the sensors and if there were any problems they encountered.

Up to ten children aged between 10-12 years will be invited to participate in the study.

In addition the following information will be collected from children giving assent:

- Age, Ethnicity and Gender.

What are the discomforts and risks?
There are no discomforts or risks for the school.

WHAT ARE THE BENEFITS?

Physical activity is essential for children as it aids in the development of motor skills, brain development and decreases the risk of developing obesity and other chronic diseases such as Type 2 diabetes and Cardiovascular disease. Research shows that many New Zealand children are currently not achieving the recommended 60 minutes of moderate physical activity on most, if not all, days of the week. Measuring children's daily levels of physical activity and inactivity is important for monitoring trends, assessing the effectiveness of interventions and determining the dose response relationship between activity levels and health outcomes. To accurately assess these levels measures need to be both valid and reliable. However, accurate measurement tools are costly therefore not widely used. The proposed pressure sensor is an accurate measure, which is unlikely to be subject to participant tampering, and cheaper than other gold standard measures. The sensor could be used in an academic setting to evaluate programmes and monitor levels or in a public health setting where individuals monitor their own levels of physical activity.

WHAT COMPENSATION IS AVAILABLE FOR INJURY OR NEGLIGENCE?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

HOW WILL MY PRIVACY BE PROTECTED?

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

- Individuals involved in collecting information will be required to sign a confidentiality agreement.
- Identifying information will be removed from documents.
- Forms will be kept in a secure location at AUT and separately from data collected.
- Data will be entered and stored directly onto password protected electronic databases.
- Parents and legal guardians of children will have access to all stored information relating to your child.
- Only information necessary for the purposes of this study will be collected.

Data will not be shared with any other third party that is not directly involved with the project.

WHAT ARE THE COSTS OF PARTICIPATING IN THIS RESEARCH?

There are no monetary costs to schools in the **Pressure Sensor** project. Access to the school and school roll to recruit participants will be required.

WHAT OPPORTUNITY DO I HAVE TO CONSIDER THIS INVITATION?

The decision to join in the study can be made at any time before the start of the **Pressure Sensor** project in 14 days time.

HOW DO I AGREE TO PARTICIPATE IN THIS RESEARCH?

Your consent to allow access to your school for the **Pressure Sensor** project will be indicated by signing the access form attached. Signing the access form indicates that give access to recruit children from your school.

WILL I RECEIVE FEEDBACK ON THE RESULTS OF THIS RESEARCH?

A short report will be available four weeks after the completion of the project.

WHAT DO I DO IF I HAVE CONCERNS ABOUT THIS RESEARCH?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr Erica Hinckson, erica.hinckson@aut.ac.nz, 921 9999 extension 7224

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

WHOM DO I CONTACT FOR FURTHER INFORMATION ABOUT THIS RESEARCH?

RESEARCHER CONTACT DETAILS:

Amy Curtis
School of Sport and Recreation,
Faculty of Health Sciences,
Akoranga Campus,
Auckland University of Technology,
Private Bag 92006, Auckland 1020.
Phone 921 9999 extension 7848
Email: acurtis@aut.ac.nz.

PROJECT SUPERVISOR CONTACT DETAILS:

Dr Erica Hinckson,

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

Approved by the Auckland University of Technology Ethics Committee on 8th May 2011 AUTEC Reference number 11/75

APPENDIX B: PRINCIPAL INFORMATION SHEET FOR CHILDREN WITH INTELLECTUAL DISABILITIES

Principal's Information Sheet

DATE INFORMATION SHEET PRODUCED:
29th March 2011

PROJECT TITLE
A novel pressure sensor to objectively measure physical activity in children

AN INVITATION
Hello my name is Amy Curtis, I am a Master's candidate at AUT University, and I would like your school to take part in my **Pressure Sensor** research project. Thank you for considering joining this research project. Please read the following information sheet carefully before deciding to take part. If you have any questions please ask.

Amy Curtis
School of Sport and Recreation,
Faculty of Health Sciences,
Akoranga Campus,
Auckland University of Technology,
Private Bag 92006, Auckland 1020.
Phone 921 9999 extension 7848
Email: acurtis@aut.ac.nz

The purpose of the **Pressure Sensor** project is to develop a valid and reliable shoe-mounted sensor for the objective measurement of physical activity in all children, including those with learning and/or behavioural disabilities.

I will be examining the feasibility of pressure sensors to measure daily step counts and intensity in children living with learning and/or behavioural disabilities. A pressure sensor will be fitted into the sole of children's favourite shoe, which they will be asked to wear during their waking hours for 7 days. Children's parents and carers will be required to fill out activity logs twice daily to capture their physical activity levels, for at least three days that children are wearing the sensor.

I will require access to your school to recruit children onto the project. I am going to be randomly selecting children to participate so would need access to your Year 7&8 roll. Parents of selected children will be mailed out information sheets, consent and assent forms. A child may not join in this study without the approval of a parent or legal guardian and the consent of the child. Your school is free to withdraw consent and stop at any time without changing your present and / or future involvement with AUT University. Your consent to allow the **Pressure Sensor** Project to access your school will be indicated by signing the consent form provided.

WHAT IS THE PURPOSE OF THIS RESEARCH?

The purpose of this research is to develop a cost-effective, valid and reliable, objective measure of physical activity. Subjective measures of physical activity, such as self-report questionnaires and time use diaries, are a cheap measure and can provide activity settings and type of physical activities, however, can be unreliable as they are subject to self-reporting bias, memory, understanding and peer pressure. Objective measures such as Direct Observation, Accelerometers and Pedometer, are often more reliable. However, direct observation is time consuming, accelerometers are expensive and do not provide setting and type of physical activity and pedometers can be subject to participant tampering and only give an indication of daily step count. Furthermore, these objective measures may alter usual behaviours as participants are aware that they are being measured. More issues are present when measuring populations with behavioural and/or learning disabilities as researcher burden and refusal of children to be instrumented were regularly quoted as limitations. Wearing motion sensors requiring hip or wrist placement are also not suitable as children tend to discard or refuse to wear them.

As children's most common physical activity is walking, a sensor that is placed in the sole of the shoe that can detect steps might be a way to objectively measure daily activity in all children, including children with behaviour and learning disabilities (who are not wheelchair bound). The proposed shoe sensor will not be subject to participant tampering as it will detect the amplitude and duration of force at a certain level, rather than movements, therefore a step bearing the child's weight will need to be taken in order for it to register in the sensor. Additionally, children can easily forget they are being measured as the sensor will be placed in their shoe and will be less likely to alter usual behaviours, potentially making it a more reliable measure of physical activity than pedometers.

HOW WAS I CHOSEN FOR THIS INVITATION?

Your primary school was randomly selected and invited to participate in the **Pressure Sensor** project.

The **Pressure Sensor** project is inviting the first ten consenting children aged ten to twelve years to join the project.

WHAT WILL HAPPEN IN THIS RESEARCH?

Parents and whanau are invited to be present at the time pressure sensors and diaries are given to their child. The testing will take place over 7 days in the end of Term 3. Children will be fitted with a pressure sensor in the sole of their favourite shoe and requested to wear this shoe upon waking during the 7 days. Children will also be provided an activity diary for their parents and carers to log their activity twice daily for a minimum of 3 days (2 weekdays and 1 weekend). At the end of 7 days parents, teachers and carers will be asked some simple questions on how they found wearing the sensors and if there were any problems they encountered.

Up to ten children aged between 10-12 years will be invited to participate in the study.

In addition the following information will be collected from children giving assent:

- Age, Ethnicity and Gender.

What are the discomforts and risks?
There are no discomforts or risks for the school.

WHAT ARE THE BENEFITS?

Physical activity is essential for children as it aids in the development of motor skills, brain development and decreases the risk of developing obesity and other chronic diseases such as Type 2 diabetes and Cardiovascular disease. Research shows that many New Zealand children are currently not achieving the recommended 60 minutes of moderate physical activity on most, if not all, days of the week. Additionally, due to measurement difficulties, little information is available on the physical activity levels of children living with learning and/or behavioural disabilities. Measuring children's daily levels of physical activity and inactivity is important for monitoring trends, assessing the effectiveness of interventions and determining the dose response relationship between activity levels and health outcomes. To accurately assess these levels measures need to be both valid and reliable. However, accurate measurement tools are costly therefore not widely used. The proposed pressure sensor is an accurate measure, which is unlikely to be subject to participant tampering, and cheaper than other gold standard measures. The sensor could be used with all populations, in an academic or public health setting.

WHAT COMPENSATION IS AVAILABLE FOR INJURY OR NEGLIGENCE?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

HOW WILL MY PRIVACY BE PROTECTED?

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

- Individuals involved in collecting information will be required to sign a confidentiality agreement.
- Identifying information will be removed from documents.
- Forms will be kept in a secure location at AUT and separately from data collected.
- Data will be entered and stored directly onto password protected electronic databases.
- Parents and legal guardians of children will have access to all stored information relating to your child.
- Only information necessary for the purposes of this study will be collected.

Data will not be shared with any other third party that is not directly involved with the project.

WHAT ARE THE COSTS OF PARTICIPATING IN THIS RESEARCH?

There are no monetary costs to schools in the **Pressure Sensor** project. Access to the school and school roll to recruit participants will be required.

WHAT OPPORTUNITY DO I HAVE TO CONSIDER THIS INVITATION?

The decision to join in the study can be made at any time before the start of the **Pressure Sensor** project in 14 days time.

HOW DO I AGREE TO PARTICIPATE IN THIS RESEARCH?

Your consent to allow access to your school for the **Pressure Sensor** project will be indicated by signing the access form attached. Signing the access form indicates that give access to recruit children from your school.

WILL I RECEIVE FEEDBACK ON THE RESULTS OF THIS RESEARCH?

A short report will be available four weeks after the completion of the project.

WHAT DO I DO IF I HAVE CONCERNS ABOUT THIS RESEARCH?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr Erica Hinckson, erica.hinckson@aut.ac.nz, 921 9999 extension 7224

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

WHOM DO I CONTACT FOR FURTHER INFORMATION ABOUT THIS RESEARCH?

RESEARCHER CONTACT DETAILS:

Amy Curtis
School of Sport and Recreation,
Faculty of Health Sciences,
Akoranga Campus,
Auckland University of Technology,
Private Bag 92006, Auckland 1020.
Phone 921 9999 extension 7848
Email: acurtis@aut.ac.nz.

PROJECT SUPERVISOR CONTACT DETAILS:

Dr Erica Hinckson,

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

Approved by the Auckland University of Technology Ethics Committee on 8^th^ May 2011 AUTEC Reference number 11/75

Appendix C: Parent Information Sheet For Typically developing children

Participant Information Sheet

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

DATE INFORMATION SHEET PRODUCED:
29th March 2011

PROJECT TITLE
A novel pressure sensor to objectively measure physical activity in children

AN INVITATION
Hello my name is Amy Curtis, I am a Master's candidate at AUT University, and I would like you and your child to take part in my **Pressure Sensor** research project. Thank you for considering joining this research project. Please read the following information sheet carefully before deciding to take part. If you have any questions please ask.

Amy Curtis
School of Sport and Recreation,
Faculty of Health Sciences,
Akoranga Campus,
Auckland University of Technology,
Private Bag 92006, Auckland 1020.
Phone 921 9999 extension 7848
Email: acurtis@aut.ac.nz

The purpose of the **Pressure Sensor** project is to develop a valid and reliable shoe-mounted sensor for the objective measurement of physical activity in children.

I will be testing the validity, reliability and feasibility of pressure sensors to measure daily step counts and intensity in children. During one afternoon children will be required to attend validity and reliability testing at AUT. Children will wear sensors and pedometers while walking on the treadmill at different speeds. To test feasibility, children will also be provided with sensors to wear for one week in their favourite shoe as well as wearing a pedometer. Children will be required to fill out activity logs twice daily to capture their physical activity levels, for at least 3 days while wearing the sensors.

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

WHAT IS THE PURPOSE OF THIS RESEARCH?

The purpose of this research is to develop a cost-effective, valid and reliable, objective measure of physical activity. Subjective measures of physical activity, such as self-report questionnaires and time use diaries, are a cheap measure and can provide activity settings and type of physical activities, however, can be unreliable as they are subject to self-reporting bias, memory, understanding and peer pressure. Objective measures such as Direct Observation, Accelerometers and Pedometer, are often more reliable. However, direct observation is time consuming, accelerometers are expensive and do not provide setting and type of physical activity and pedometers can be subject to participant tampering and only give an indication of daily step count. Furthermore, these objective measures may alter usual behaviours as participants are aware that they are being measured.

As children's most common physical activity is walking, a sensor that is placed in the sole of the shoe that can detect steps might be a way to objectively measure daily activity in all children. The proposed shoe sensor will not be subject to participant tampering as it will detect the amplitude and duration of force at a certain level, rather than movements, therefore a step bearing the child's weight will need to be taken in order for it to register in the sensor. Additionally, children can easily forget they are being measured as the sensor will be placed in their shoe and will be less likely to alter usual behaviours, potentially making it a more reliable measure of physical activity than pedometers.

HOW WAS I CHOSEN FOR THIS INVITATION?

Your child's primary school was randomly selected and invited to participate in the **Pressure Sensor** project.

The **Pressure Sensor** project is inviting the first ten consenting children aged ten to twelve years to join the project.

WHAT WILL HAPPEN IN THIS RESEARCH?

Parents and whanau are invited to be present during treadmill testing, and at the time pressure sensors and diaries are given to their child.

The validity and reliability testing phase will take place during one afternoon in the start of Term 2. The first ten consenting children will be required to wear a pedometer and pressure sensor while walking on the treadmill at slow, medium and fast pace. During the time children are walking step counts will also be observed.

The feasibility testing phase will take place over 7 days in the end of Term 3. Children will be fitted with a pressure sensor in the sole of their favourite shoe and requested to wear this shoe upon waking during the 7 days. During the 7 days children will also be given a pedometer to wear to compare pedometer step counts with sensor counts. While we request that participants take reasonable care with pressure sensors and pedometers please do not feel anxious about losing or breaking these.

Children will also be provided an activity diary to log their activity twice daily for a minimum of 3 days (2 weekdays and 1 weekend). At the end of 7 days children will be asked some simple questions on how they found wearing the sensors and if there were any problems they encountered.

Up to ten children aged between 10-12 years will be invited to participate in the study.
In addition the following information will be collected from children giving assent:

- Age, Ethnicity and Gender.

WHAT ARE THE DISCOMFORTS AND RISKS?

There are no discomforts or risks for children participating on the project. During validity and reliability testing, children will be required to attend AUT for one afternoon whereby they will undertake a short walk on the treadmill at fast, medium and slow pace.
During feasibility testing, children will be required for 30 minutes in the morning of one weekday in which to receive their sensor and activity diary and taught how to use these. During the seven days they are wearing sensors children will be further required to spend a few minutes during lunch time and before bed filling out their activity diaries. After seven days, children will be required for a further 30 minutes in the morning for a short interview and to give the sensors and diaries back.

HOW WILL THESE DISCOMFORTS AND RISKS BE ALLEVIATED?

Discomforts and risks of harm to the children are the same for any normal school day or weekend day. Supervision and minimisation of risk are under the control of the school.

WHAT ARE THE BENEFITS?

Physical activity is essential for children as it aids in the development of motor skills, brain development and decreases the risk of developing obesity and other chronic diseases such as Type 2 diabetes and Cardiovascular disease. Research shows that many New Zealand children are currently not achieving the recommended 60 minutes of moderate physical activity on most, if not all, days of the week. Measuring children’s daily levels of physical activity and inactivity is important for monitoring trends, assessing the effectiveness of interventions and determining the dose response relationship between activity levels and health outcomes. To accurately assess these levels measures need to be both valid and reliable. However, accurate measurement tools are costly therefore not widely used. The proposed pressure sensor is an accurate measure, which is unlikely to be subject to participant tampering, and cheaper than other gold standard measures. The sensor could be used with all populations, in an academic or public health setting.

WHAT COMPENSATION IS AVAILABLE FOR INJURY OR NEGLIGENCE?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

HOW WILL MY PRIVACY BE PROTECTED?

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

- Individuals involved in collecting information will be required to sign a confidentiality agreement.
- Identifying information will be removed from documents.

- Forms will be kept in a secure location at AUT and separately from data collected.
- Data will be entered and stored directly onto password protected electronic databases.
- Parents and legal guardians of children will have access to all stored information relating to your child.
- Only information necessary for the purposes of this study will be collected.

Data will not be shared with any other third party that is not directly involved with the project.

WHAT ARE THE COSTS OF PARTICIPATING IN THIS RESEARCH?

There are no monetary costs to parents in the **Pressure Sensor** project. Children will be required for 30 minutes in the morning to be given sensors and diaries, then for a further 30 minutes after seven days to provide feedback and return sensors and diaries. Children will be required for a few minutes daily, during the seven days, to fill out their activity diaries.

WHAT OPPORTUNITY DO I HAVE TO CONSIDER THIS INVITATION?

The decision to join in the study can be made at any time before the start of the **Pressure Sensor** project in 14 days time.

HOW DO I AGREE TO PARTICIPATE IN THIS RESEARCH?

Your consent to allow your child to join in the **Pressure Sensor** project will be indicated by signing the consent form attached and returning it to your child's teacher. Signing the consent form indicates that you have given your consent freely to join the Project and that there has been no coercion or inducement to allow your child to join. Full consent for your child to join in the Project is conditional on your child also agreeing to join.

Your child joins the study only if they wish to. A child may not join in this study without the approval of a parent or legal guardian and the consent of the child. Your child is free to withdraw consent and stop at any time without changing your present and / or future involvement with the school or AUT University.

WILL I RECEIVE FEEDBACK ON THE RESULTS OF THIS RESEARCH?

A short report will be available four weeks after the completion of the project.

WHAT DO I DO IF I HAVE CONCERNS ABOUT THIS RESEARCH?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr Erica Hinckson, erica.hinckson@aut.ac.nz, 921 9999 extension 7224

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

WHOM DO I CONTACT FOR FURTHER INFORMATION ABOUT THIS RESEARCH?

RESEARCHER CONTACT DETAILS:

Amy Curtis
School of Sport and Recreation,

Faculty of Health Sciences,
Akoranga Campus,
Auckland University of Technology,
Private Bag 92006, Auckland 1020.
Phone 921 9999 extension 7848
Email: acurtis@aut.ac.nz

PROJECT SUPERVISOR CONTACT DETAILS:

Dr Erica Hinckson,

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

Approved by the Auckland University of Technology Ethics Committee on 8th May 2011 AUTEC Reference number 11/75

APPENDIX D: PARENT INFORMATION SHEET FOR CHILDREN WITH INTELLECTUAL DISABILITIES

Participant Information Sheet

DATE INFORMATION SHEET PRODUCED:
29th March 2011

PROJECT TITLE
A novel pressure sensor to objectively measure physical activity in children

AN INVITATION
Hello my name is Amy Curtis, I am a Master's candidate at AUT University, and I would like you and your child to take part in my **Pressure Sensor** research project. Thank you for considering joining this research project. Please read the following information sheet carefully before deciding to take part. If you have any questions please ask.

Amy Curtis
School of Sport and Recreation,
Faculty of Health Sciences,
Akoranga Campus,
Auckland University of Technology,
Private Bag 92006, Auckland 1020.
Phone 921 9999 extension 7848
Email: acurtis@aut.ac.nz

The purpose of the **Pressure Sensor** project is to develop a valid and reliable shoe-mounted sensor for the objective measurement of physical activity in all children, including those with learning and/or behavioural disabilities.

I will be examining the validity of pressure sensors to measure daily step counts in children living with learning and/or behavioural disabilities. A pressure sensor will be fitted into the sole of children's favourite shoe, which they will be asked to wear during a one hour classroom lesson. Children's step counts will be directly observed then recorded and compared to data collected by the shoe sensors.

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

WHAT IS THE PURPOSE OF THIS RESEARCH?

The purpose of this research is to develop a cost-effective, valid and reliable, objective measure of physical activity. Subjective measures of physical activity, such as self-report questionnaires and time use diaries, are a cheap measure and can provide activity settings and type of physical activities, however, can be unreliable as they are subject to self-reporting bias, memory, understanding and peer pressure. Objective measures such as Direct Observation, Accelerometers and Pedometer, are often more reliable. However, direct observation is time consuming, accelerometers are expensive and do not provide setting and type of physical activity and pedometers can be subject to participant tampering and only give an indication of daily step count. Furthermore, these objective measures may alter usual behaviours as participants are aware that they are being measured. More issues are present when measuring populations with behavioural and/or learning disabilities as researcher burden and refusal of children to be instrumented were regularly quoted as limitations. Wearing motion sensors requiring hip or wrist placement are also not suitable as children tend to discard or refuse to wear them.

As children's most common physical activity is walking, a sensor that is placed in the sole of the shoe that can detect steps might be a way to objectively measure daily activity in all children, including children with behaviour and learning disabilities (who are not wheelchair bound). The proposed shoe sensor will not be subject to participant tampering as it will detect the amplitude and duration of force at a certain level, rather than movements, therefore a step bearing the child's weight will need to be taken in order for it to register in the sensor. Additionally, children can easily forget they are being measured as the sensor will be placed in their shoe and will be less likely to alter usual behaviours, potentially making it a more reliable measure of physical activity than pedometers.

HOW WAS I CHOSEN FOR THIS INVITATION?

Your child's primary school was randomly selected and invited to participate in the **Pressure Sensor** project.

The **Pressure Sensor** project is inviting the first ten consenting children aged ten to twelve years to join the project.

WHAT WILL HAPPEN IN THIS RESEARCH?

Parents and whanau are invited to be present at the time pressure sensors are given to their child. The testing will take place during school time in the start of Term 1. Children will be fitted with a pressure sensor in the sole of their favourite shoe and requested to wear this shoe during a classroom lesson. While we request that participants take reasonable care with pressure sensors please do not feel anxious about breaking these. Children will also be directly observed and their movements recorded and compared to data collected by sensors.

Up to ten children aged between 10-12 years will be invited to participate in the study.

In addition the following information will be collected from children giving assent:

- Age, Ethnicity and Gender.

WHAT ARE THE DISCOMFORTS AND RISKS?

There are no discomforts or risks for children participating on the project. Children will be required for one morning during the weekday for the sensor to be fitted to their shoe and to undertake a classroom lesson while wearing the sensor.

HOW WILL THESE DISCOMFORTS AND RISKS BE ALLEVIATED?

Discomforts and risks of harm to the children are the same for any normal school day or weekend day. Supervision and minimisation of risk are under the control of the school.

WHAT ARE THE BENEFITS?

Physical activity is essential for children as it aids in the development of motor skills, brain development and decreases the risk of developing obesity and other chronic diseases such as Type 2 diabetes and Cardiovascular disease. Research shows that many New Zealand children are currently not achieving the recommended 60 minutes of moderate physical activity on most, if not all, days of the week. Additionally, due to measurement difficulties, little information is available on the physical activity levels of children living with learning and/or behavioural disabilities. Measuring children's daily levels of physical activity and inactivity is important for monitoring trends, assessing the effectiveness of interventions and determining the dose response relationship between activity levels and health outcomes. To accurately assess these levels measures need to be both valid and reliable. However, accurate measurement tools are costly therefore not widely used. The proposed pressure sensor is an accurate measure, which is unlikely to be subject to participant tampering, and cheaper than other gold standard measures. The sensor could be used with all populations, in an academic or public health setting.

WHAT COMPENSATION IS AVAILABLE FOR INJURY OR NEGLIGENCE?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

HOW WILL MY PRIVACY BE PROTECTED?

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

- Individuals involved in collecting information will be required to sign a confidentiality agreement.
- Identifying information will be removed from documents.
- Forms will be kept in a secure location at AUT and separately from data collected.
- Data will be entered and stored directly onto password protected electronic databases.
- Parents and legal guardians of children will have access to all stored information relating to your child.
- Only information necessary for the purposes of this study will be collected.

Data will not be shared with any other third party that is not directly involved with the project.

WHAT ARE THE COSTS OF PARTICIPATING IN THIS RESEARCH?

There are no monetary costs to parents in the **Pressure Sensor** project. Children will be required for one morning during the school week.

WHAT OPPORTUNITY DO I HAVE TO CONSIDER THIS INVITATION?

The decision to join in the study can be made at any time before the start of the **Pressure Sensor** project in 14 days time.

HOW DO I AGREE TO PARTICIPATE IN THIS RESEARCH?

Your consent to allow your child to join in the **Pressure Sensor** project will be indicated by signing the consent form attached and returning it to your child's teacher. Signing the consent form indicates that you have given your consent freely to join the Project and that there has been no coercion or inducement to allow your child to join. Full consent for your child to join in the Project is conditional on your child also agreeing to join.

Your child joins the study only if they wish to. A child may not join in this study without the approval of a parent or legal guardian and the consent of the child. Your child is free to withdraw consent and stop at any time without changing your present and / or future involvement with the school or AUT University.

WILL I RECEIVE FEEDBACK ON THE RESULTS OF THIS RESEARCH?

A short report will be available four weeks after the completion of the project.

WHAT DO I DO IF I HAVE CONCERNS ABOUT THIS RESEARCH?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr Erica Hinckson, erica.hinckson@aut.ac.nz, 921 9999 extension 7224

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

WHOM DO I CONTACT FOR FURTHER INFORMATION ABOUT THIS RESEARCH?

RESEARCHER CONTACT DETAILS:

Amy Curtis
School of Sport and Recreation,
Faculty of Health Sciences,
Akoranga Campus,
Auckland University of Technology,
Private Bag 92006, Auckland 1020.
Phone 921 9999 extension 7848
Email: acurtis@aut.ac.nz

PROJECT SUPERVISOR CONTACT DETAILS:

Dr Erica Hinckson,

School of Sport and Recreation,
Faculty of Health Sciences,
Akoranga Campus,
Auckland University of Technology,
Private Bag 92006, Auckland 1020.

Phone 921 9999 extension 7224
Email: erica.hinckson@aut.ac.nz

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Approved by the Auckland University of Technology Ethics Committee on 8th May 2011 AUTEC Reference number 11/75

APPENDIX E: INFORMATION SHEET FOR TYPICALLY DEVELOPING CHILDREN

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

PRESSURE SENSOR

INFORMATION SHEET AND ASSENT FORM FOR CHILDREN

(parent/caregivers please read to children)

This form will be kept for a period of 6 years

Hello – my name is Amy Curtis.

I am conducting a project on how many steps children take. I would like you to come into AUT University on one afternoon to walk on a treadmill for a short time at different speeds. While you are walking I would like you to wear a special sole in your shoe and a pedometer which will tell me how many steps you have taken. Is that ok?

Please circle YES or circle NO.

I would also like to give you a new sole to wear in your favourite shoe for seven days. Is that okay?

Please circle YES or circle NO.

While you are wearing your new sole I will need to learn about the different physical activities you did for a few days. I will need you to fill out a diary of the time you play games, sport or are physically active and how long you do these activities for.

Would you like to fill out a diary of the physical activities games you do for 3 days?

Please circle YES or circle NO.

I will also need you to wear this pedometer on your hip for seven days while you are wearing the sensor. Will this be ok?

Please circle YES or circle NO.

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

(Child's name)

(Parent / Caregiver Signature)

(Date)

If you feel that you understand what the project is about please give this form back to your teacher at school tomorrow.

Amy Curtis (Researcher)

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor,

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

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

Approved by the Auckland University of Technology Ethics Committee on 8th May 2011 AUTEC Reference number 11/75

APPENDIX F: INFORMATION SHEET FOR CHILDREN WITH INTELLECTUAL DISABILITIES

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

PRESSURE SENSOR

INFORMATION SHEET AND ASSENT FORM FOR CHILDREN

(parent/caregivers please read to children)

This form will be kept for a period of 6 years

Hello – my name is Amy Curtis.

I am conducting a project on how many steps children take. I would like to give you a new sole to wear in your favourite shoe for the morning. Is that okay?

Please circle YES or circle NO .

While you are wearing the sensor is it okay if I watch how many steps you take?

Please circle YES or circle NO .

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

(Child's name)

(Parent / Caregiver Signature)

(Date)

If you feel that you understand what the project is about please give this form back to your teacher at school tomorrow.

Amy Curtis (Researcher)

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor,

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

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

Approved by the Auckland University of Technology Ethics Committee on 8th May 2011 AUTEC Reference number 11/75

APPENDIX G: SCHOOL ACCESS CONSENT FORM

SCHOOL ACCESS FORM

Project title: **A novel pressure sensor to objectively measure physical activity in children**

Project Supervisor: **Dr Erica Hinckson**

Researcher: **Amy Curtis**

○ I have read and understood the information provided about this research project in the Information Sheet dated 29th March 2011.

○ I have had an opportunity to ask questions and to have them answered.

○ I understand that access to the students in my school will be required.

○ I understand that access to my school roll will be required.

○ I agree to providing access to my school for this research.

○ I wish to receive a copy of the report from the research (please tick one):

Yes○ No○

School Name:

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Principal's signature:

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Principal's name:

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Principal's Contact Details:

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Date:

Approved by the Auckland University of Technology Ethics Committee on 8th May 2011 AUTEC Reference number 11/75

Note: The Participant should retain a copy of this form.

APPENDIX H: PARENT CONSENT OF TYPICALLY DEVELOPING CHILDREN TO PARTICIPATION IN RESEARCH

PARENT / GUARDIAN CONSENT FORM

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project title: **A novel pressure sensor to objectively measure physical activity in children**

Project Supervisor: **Dr Erica Hinckson**

Researcher: **Amy Curtis**

- ○ I have read and understood the information provided about this research project in the Information Sheet dated 29th March 2011
- ○ I have had an opportunity to ask questions and to have them answered.
- ○ I understand that my child/children will take part in an afternoon of validity and reliability testing, including, walking on a treadmill, wearing a pedometer, accelerometer and shoe sensor.
- ○ I understand that my child/children will wear a pedometer and the sensor in their favourite shoe for 7 days.
- ○ I understand that my child/children will fill out an activity diary for three days while wearing the sensors and pedometers.
- ○ I understand that my child/children will take part in a brief interview after the seven days which will be recorded. Recordings will be destroyed once data has been extracted.
- ○ I understand that I may withdraw my child/children or any information that we have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- ○ If my child/children withdraws I understand that all relevant information including recordings and information will be destroyed.
- ○ I agree to my child/children taking part in this research.
- ○ I wish to receive a copy of the report from the research (please tick one):

Yes○ No○

Child / Children's Name(s):

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Parent/Guardian's signature:

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Parent/Guardian's name:

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Parent/Guardian's Contact Details:

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Date:

Approved by the Auckland University of Technology Ethics Committee on 8th May 2011 AUTEC Reference number 11/75

Note: The Participant should retain a copy of this form.

APPENDIX I: PARENT CONSENT OF CHILDREN WITH INTELLECTUAL DISABILITIES TO PARTICIPATION IN RESEARCH

PARENT / GUARDIAN CONSENT FORM

Project title: **A novel pressure sensor to objectively measure physical activity in children**

Project Supervisor: **Dr Erica Hinckson**

Researcher: **Amy Curtis**

○ I have read and understood the information provided about this research project in the Information Sheet dated 29th March 2011

○ I have had an opportunity to ask questions and to have them answered.

○ I understand that my child/children will wear a sensor in their favourite shoe for one morning during school.

○ I understand that my child's step counts will be directly observed during a classroom lesson while wearing the sensor.

○ I understand that I may withdraw my child/children or any information that we have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.

○ If my child/children withdraws I understand that all relevant information including recordings and information will be destroyed.

○ I agree to my child/children taking part in this research.

○ I wish to receive a copy of the report from the research (please tick one):

Yes○ No○

Child / Children's Name(s):

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Parent/Guardian's signature:

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Parent/Guardian's name:

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Parent/Guardian's Contact Details:

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Date:

Approved by the Auckland University of Technology Ethics Committee on 8th May 2011 AUTEC Reference number 11/75

Note: The Participant should retain a copy of this form.

APPENDIX J: APPROVAL LETTER FROM ETHICS COMMITTEE

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

MEMORANDUM

Auckland University of Technology Ethics Committee

(AUTEC)

To:	Erica Hinckson
From:	**Dr Rosemary Godbold and Madeline Banda** Executive Secretary, AUTEC
Date:	27 May 2011
Subject:	Ethics Application Number 11/75 **A novel pressure sensor to objectively measure physical activity in children.**

Dear Erica

Thank you for providing written evidence as requested. We are pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC) at their meeting on 11 April 2011 and that on 20 May 2011, we approved your ethics application. This delegated approval is made in accordance with section 5.3.2.3 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement at AUTEC's meeting on 13 June 2011.

Your ethics application is approved for a period of three years until 20 May 2014.

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

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/research/research-ethics/ethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 20 May 2014;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/research/research-ethics/ethics. This report is to be submitted either when the approval expires on 20 May 2014 or on completion of the project, whichever comes sooner;

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are reminded that, as applicant, you are responsible for ensuring that research undertaken under this approval occurs within the parametres outlined in the approved application.

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

When communicating with us about this application, we ask that you use the application number and study title to enable us to provide you with prompt service. Should you have any further enquiries regarding this matter, you are welcome to contact Charles Grinter, Ethics Coordinator, by email at ethics@aut.ac.nz or by telephone on 921 9999 at extension 8860.

On behalf of AUTEC and ourselves, we wish you success with your research and look forward to reading about it in your reports.

Yours sincerely

Dr Rosemary Godbold and Madeline Banda

Executive Secretary

Auckland University of Technology Ethics Committee

Cc: Amy Curtis acurtis@aut.ac.nz

APPENDIX K: EXAMPLE OF DATA COLLECTED FROM THE SENSOR PRESSURE SYSTEM OVER SEVEN DAYS

14/12/11:18:0:0	Heel=10	Outside=9	Inside=24
14/12/11:19:0:0	Heel=20	Outside=15	Inside=16
14/12/11:20:0:0	Heel=0	Outside=0	Inside=0
14/12/11:21:0:0	Heel=0	Outside=0	Inside=0
14/12/11:22:0:0	Heel=0	Outside=0	Inside=0
14/12/11:23:0:0	Heel=0	Outside=0	Inside=0
15/12/11:0:0:0	Heel=0	Outside=0	Inside=0
15/12/11:1:0:0	Heel=0	Outside=0	Inside=0
15/12/11:2:0:0	Heel=0	Outside=0	Inside=0
15/12/11:3:0:0	Heel=0	Outside=0	Inside=0
15/12/11:4:0:0	Heel=0	Outside=0	Inside=0
15/12/11:5:0:0	Heel=0	Outside=0	Inside=0
15/12/11:6:0:0	Heel=0	Outside=0	Inside=0
15/12/11:7:0:0	Heel=0	Outside=0	Inside=0
15/12/11:8:0:0	Heel=0	Outside=0	Inside=0
15/12/11:9:0:0	Heel=5	Outside=7	Inside=9
15/12/11:10:0:0	Heel=11	Outside=11	Inside=10
15/12/11:11:0:0	Heel=0	Outside=0	Inside=0
15/12/11:12:0:0	Heel=27	Outside=25	Inside=24
15/12/11:13:0:0	Heel=49	Outside=51	Inside=44
15/12/11:14:0:0	Heel=10	Outside=31	Inside=5
15/12/11:15:0:0	Heel=12	Outside=12	Inside=10
15/12/11:16:0:0	Heel=27	Outside=23	Inside=19
15/12/11:17:0:0	Heel=27	Outside=23	Inside=19
15/12/11:18:0:0	Heel=76	Outside=48	Inside=32
15/12/11:19:0:0	Heel=127	Outside=36	Inside=7
15/12/11:20:0:0	Heel=163	Outside=110	Inside=105
15/12/11:21:0:0	Heel=135	Outside=125	Inside=110
15/12/11:22:0:0	Heel=0	Outside=0	Inside=0
15/12/11:23:0:0	Heel=0	Outside=0	Inside=0
16/12/11:0:0:0	Heel=0	Outside=0	Inside=0
16/12/11:1:0:0	Heel=0	Outside=0	Inside=0
16/12/11:2:0:0	Heel=0	Outside=0	Inside=0
16/12/11:3:0:0	Heel=4	Outside=0	Inside=0
16/12/11:4:0:0	Heel=0	Outside=0	Inside=0
16/12/11:5:0:0	Heel=3	Outside=0	Inside=0
16/12/11:6:0:0	Heel=7	Outside=0	Inside=0
16/12/11:7:0:0	Heel=7	Outside=0	Inside=0
16/12/11:8:0:0	Heel=14	Outside=0	Inside=0
16/12/11:9:0:0	Heel=4	Outside=0	Inside=0
16/12/11:10:0:0	Heel=5	Outside=2	Inside=4
16/12/11:11:0:0	Heel=28	Outside=2	Inside=3
16/12/11:12:0:0	Heel=92	Outside=2	Inside=5
16/12/11:13:0:0	Heel=41	Outside=3	Inside=3

16/12/11:14:0:0	Heel=0	Outside=0	Inside=0
16/12/11:15:0:0	Heel=1647	Outside=207	Inside=198
16/12/11:16:0:0	Heel=88	Outside=667	Inside=659
16/12/11:17:0:0	Heel=0	Outside=1797	Inside=1588
16/12/11:18:0:0	Heel=0	Outside=1225	Inside=1063
16/12/11:19:0:0	Heel=0	Outside=584	Inside=516
16/12/11:20:0:0	Heel=0	Outside=2	Inside=1
16/12/11:21:0:0	Heel=0	Outside=0	Inside=0
16/12/11:22:0:0	Heel=0	Outside=0	Inside=0
16/12/11:23:0:0	Heel=0	Outside=0	Inside=0
17/12/11:0:0:0	Heel=0	Outside=0	Inside=0
17/12/11:1:0:0	Heel=0	Outside=0	Inside=0
17/12/11:2:0:0	Heel=0	Outside=0	Inside=0
17/12/11:3:0:0	Heel=0	Outside=0	Inside=0
17/12/11:4:0:0	Heel=0	Outside=0	Inside=0
17/12/11:5:0:0	Heel=0	Outside=0	Inside=0
17/12/11:6:0:0	Heel=0	Outside=0	Inside=0
17/12/11:7:0:0	Heel=0	Outside=0	Inside=0
17/12/11:8:0:0	Heel=0	Outside=0	Inside=0
17/12/11:9:0:0	Heel=0	Outside=31	Inside=35
17/12/11:10:0:0	Heel=0	Outside=43	Inside=45
17/12/11:11:0:0	Heel=0	Outside=99	Inside=63
17/12/11:12:0:0	Heel=0	Outside=131	Inside=133
17/12/11:13:0:0	Heel=0	Outside=0	Inside=0
17/12/11:14:0:0	Heel=0	Outside=410	Inside=446
17/12/11:15:0:0	Heel=0	Outside=1358	Inside=1335
17/12/11:16:0:0	Heel=0	Outside=0	Inside=0
17/12/11:17:0:0	Heel=0	Outside=0	Inside=0
17/12/11:18:0:0	Heel=0	Outside=0	Inside=0
17/12/11:19:0:0	Heel=0	Outside=0	Inside=0
17/12/11:20:0:0	Heel=0	Outside=0	Inside=0
17/12/11:21:0:0	Heel=0	Outside=0	Inside=0
17/12/11:22:0:0	Heel=0	Outside=0	Inside=0
17/12/11:23:0:0	Heel=0	Outside=0	Inside=0
18/12/11:0:0:0	Heel=0	Outside=0	Inside=0
18/12/11:1:0:0	Heel=0	Outside=0	Inside=0
18/12/11:2:0:0	Heel=0	Outside=0	Inside=0
18/12/11:3:0:0	Heel=0	Outside=0	Inside=0
18/12/11:4:0:0	Heel=0	Outside=0	Inside=0
18/12/11:5:0:0	Heel=0	Outside=0	Inside=0
18/12/11:6:0:0	Heel=0	Outside=0	Inside=0
18/12/11:7:0:0	Heel=0	Outside=0	Inside=0
18/12/11:8:0:0	Heel=0	Outside=0	Inside=0
18/12/11:9:0:0	Heel=0	Outside=0	Inside=0
18/12/11:10:0:0	Heel=0	Outside=0	Inside=0
18/12/11:11:0:0	Heel=0	Outside=0	Inside=0

APPENDIX L: EXAMPLE ACTIVITY DIARY

My Activity Diary

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Name

This diary is for you to keep a record of all the physical activities you do for the next three days.
This includes activities which requiring moving around and that feel easy (make you breathe a bit harder than normal), hard (make you huff and puff) and activities that feel neither easy or hard (moderate):

Easy (light) activity involves little effort (e.g. slowly walking)
Neither easy or hard (moderate) activity makes you warm and slightly out of breath but not exhausted (e.g. dancing, soccer kicks, shooting hoops, climbing trees, playing on the playground)

Please:
1. Complete all sections of the diary for two school days and one weekend day.
2. Put the date of each day at the top of the page
3. Record the time you woke up in the morning and put your shoes on
4. Record the time you took your shoes off in the evening
5. Write down the time on the clock that you started doing the activity
6. Write down how long you spent doing the activity (in minutes).
7. Record how hard the activity was.

Try to fill your diary in regularly and at least twice a day, at lunch time and before bed. Otherwise, you might forget things you have done.

Below is an example of what part of a day might look like.

Day 1 Date: Friday 2nd November 2010

Time	**Activity**	**For how long (minutes)**	**How hard easy (E), moderate (m), hard (h)**
7.00am	Woke up		
7.15am	Put shoes on		
8.00am	Walking to school	20 minutes	E
10.40am	Playing on playground	10 minutes	M
10.50am	Soccer kicks	6 minutes	M
11.30am	PE class	20	M

APPENDIX M: SAMPLE INTERVIEW QUESTIONS

Children without disabilities:

Did you have any problems wearing the same shoes for a week?
Did you notice any difference in your shoe when you were wearing the sensor?
Did you remember that you were wearing the sensor?
Were there any activities you did where you couldn't wear your shoes?
Were there any physical activities you did that the SPS wouldn't have picked up?
Can you explain the times in which you had to take your shoes off?

Parent/caregiver of children without disabilities:

Did your child have any problems wearing the same shoes for a week?
Did you child notice any difference in their shoe when they were wearing the sensor?
Were there any activities they may have done where they couldn't wear your shoes?
Were there any physical activities they did that the SPS wouldn't have picked up?
Can you explain the times in which they had to take their shoes off?

APPENDIX N: EXAMPLE OF DATA COLLECTED FROM VALIDITY TESTING IN CHILDREN WITH INTELLECTUAL DISABILITIES

21/2/12:9:37:0	Heel=6	Outside=12	Inside=7		
21/2/12:9:37:30	Heel=11	Outside=29	Inside=13		
21/2/12:9:38:0	Heel=7	Outside=11	Inside=7		
21/2/12:9:38:30	Heel=14	Outside=17	Inside=15		
21/2/12:9:39:0	Heel=10	Outside=12	Inside=15		
21/2/12:9:39:30	Heel=11	Outside=25	Inside=13		
21/2/12:9:40:0	Heel=17	Outside=18	Inside=18		
21/2/12:9:40:30	Heel=20	Outside=42	Inside=20		
21/2/12:9:41:0	Heel=19	Outside=22	Inside=21		
21/2/12:9:41:30	Heel=23	Outside=33	Inside=23		
21/2/12:9:42:0	Heel=16	Outside=20	Inside=18		
21/2/12:9:42:30	Heel=19	Outside=18	Inside=19		
21/2/12:9:43:0	Heel=16	Outside=27	Inside=17		
21/2/12:9:43:30	Heel=13	Outside=13	Inside=14		
21/2/12:9:44:0	Heel=6	Outside=7	Inside=6		
21/2/12:9:44:30	Heel=14	Outside=34	Inside=16		
21/2/12:9:45:0	Heel=10	Outside=9	Inside=10	DO	3
21/2/12:9:45:30	Heel=4	Outside=3	Inside=4		
21/2/12:9:46:0	Heel=11	Outside=12	Inside=11	DO	17
21/2/12:9:46:30	Heel=3	Outside=4	Inside=3		
21/2/12:9:47:0	Heel=21	Outside=25	Inside=22	DO	27
21/2/12:9:47:30	Heel=15	Outside=18	Inside=16		

21/2/12:9:48:0	Heel=21	Outside=24	Inside=23	DO	16
21/2/12:9:48:30	Heel=29	Outside=31	Inside=27		
21/2/12:9:49:0	Heel=13	Outside=13	Inside=13	DO	9
21/2/12:9:49:30	Heel=18	Outside=22	Inside=19		
21/2/12:9:50:0	Heel=15	Outside=15	Inside=15	DO	2
21/2/12:9:50:30	Heel=10	Outside=10	Inside=11		
21/2/12:9:51:0	Heel=5	Outside=5	Inside=4	DO	7
21/2/12:9:51:30	Heel=4	Outside=4	Inside=4		
21/2/12:9:52:0	Heel=4	Outside=4	Inside=4	DO	8
21/2/12:9:52:30	Heel=6	Outside=8	Inside=8		
21/2/12:9:53:0	Heel=6	Outside=8	Inside=6	DO	15
21/2/12:9:53:30	Heel=7	Outside=7	Inside=7		
21/2/12:9:54:0	Heel=11	Outside=12	Inside=12	DO	21
21/2/12:9:54:30	Heel=14	Outside=16	Inside=15		
21/2/12:9:55:0	Heel=13	Outside=13	Inside=16		
21/2/12:9:55:30	Heel=23	Outside=23	Inside=23		
21/2/12:9:56:0	Heel=14	Outside=14	Inside=14		
21/2/12:9:56:30	Heel=18	Outside=19	Inside=18		
21/2/12:9:57:0	Heel=13	Outside=12	Inside=13		
21/2/12:9:57:30	Heel=1	Outside=3	Inside=6		
21/2/12:9:58:0	Heel=0	Outside=0	Inside=3		
21/2/12:9:58:30	Heel=0	Outside=0	Inside=2		
21/2/12:9:59:0	Heel=0	Outside=101	Inside=0		
21/2/12:9:59:30	Heel=0	Outside=0	Inside=0		

21/2/12:10:0:0	Heel=0	Outside=0	Inside=3
21/2/12:10:0:30	Heel=0	Outside=0	Inside=0
21/2/12:10:1:0	Heel=18	Outside=0	Inside=0
21/2/12:10:1:30	Heel=0	Outside=0	Inside=0
21/2/12:10:2:0	Heel=0	Outside=0	Inside=0