REFINING THE ACCELEROMETRIC MEASUREMENT OF PHYSICAL ACTIVITY

A Thesis Submitted to the College of

Graduate Studies and Research

in Partial Fulfillment of the Requirements

for the Degree of Doctorate of Philosophy

in the College of Kinesiology

University of Saskatchewan

Saskatoon

By

Dale Winfield Esliger

Permission to Use

In presenting this thesis in partial fulfillment of the requirements for a Postgraduate degree from the University of Saskatchewan, I agree that the Libraries of this University may make it freely available for inspection. I further agree that permission for copying of this thesis in any manner, in whole or in part, for scholarly purposes may be granted by the professor or professors who supervised my thesis work or, in their absence, by the Head of the Department or the Dean of the College in which my thesis work was done. It is understood that any copying or publication or use of this thesis or parts thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to the University of Saskatchewan in any scholarly use which may be made of any material in my thesis. Requests for permission to copy or to make other use of material in this thesis in whole or part should be addressed to:

Dean of the College of Kinesiology

University of Saskatchewan

87 Campus Drive

Saskatoon, Saskatchewan

S7N 5B2

Abstract

Advances in electronic sensor technologies have led to the increased use of accelerometers for measuring physical activity and sedentary behaviours. Accelerometers overcome many of the inherent limitations of other measurement methods; for example, unlike self-reported instruments, accelerometers are free from random and systematic errors introduced by respondents and interviewers, cultural tradition, and language. However, accelerometers have their own set of limitations; for example, not all accelerometers are created equal and raw accelerometer data require significant data mining procedures in order to yield meaningful outcome variables. Therefore the overall purpose of this three study dissertation was to determine the impact accelerometer model has on the development of a comprehensive physical activity and sedentary behaviour profile and to design and apply novel profiling methods in an order to gain new insights into children's physical activity.

Study One

Purpose: To determine which of the three most commonly used accelerometer models has the best intra- and inter-instrument reliability using a mechanical laboratory setup. Secondly, to determine the effect acceleration and frequency have on these reliability measures. **Methods:** Three experiments were performed. In the first, five each of the Actical, Actigraph, and RT3 accelerometers were placed on a hydraulic shaker plate and simultaneously accelerated in the vertical plane at varying accelerations and frequencies. Six different conditions of varying intensity were used to produce a range of accelerometer counts. Reliability was calculated using standard deviation, standard error of the measurement, coefficient of variation, and intraclass correlation coefficients. In

the second and third experiment, 39 Actical and 50 Actigraph accelerometers were put through the same six conditions. **Results:** Experiment One showed poor reliability in the RT3 (intra- and inter-instrument CV > 40%). Experiments Two and Three clearly indicated that the Actical (CV_{intra} = 0.5%; CV_{inter} = 5.4%) was more reliable than the Actigraph (CV_{intra} = 3.2%; CV_{inter} = 8.6%). Variability in the Actical was negatively related to the acceleration of the condition while no relationship was found between acceleration and reliability in the Actigraph. Variability in the Actigraph was negatively related to the frequency of the condition while no relationship was found between frequency and reliability in the Actical. **Conclusion:** Of the three accelerometer models measured in this study, the Actical had the best intra- and inter-instrument reliability. However, discrepant trends in the variability of Actical and Actigraph counts across accelerations and frequencies preclude the selection of a 'superior' model. More work is needed to understand why accelerometers designed to measure the same thing, behave so differently.

Study Two

The accurate measurement of habitual physical activity is fundamental to the study of the relationship between physical activity and health. However, many physical activity measurement techniques produce variables accurate to only the day level, such as total energy expenditure via self-report questionnaire, pedometer step counts or accelerometer measurements of minutes of moderate to vigorous physical activity. Monitoring technologies providing more detailed information on physical activity/sedentary behaviour can now be used to explore the relationships between health and movement frequency, intensity, and duration more comprehensively. This paper explores the activity and sedentary profile that can be acquired through objective monitoring, with a focus on accelerometry. Using previously collected objective data, a detailed physical activity profile is presented and case study examples of data utilization and interpretation are provided. The rich detail captured through comprehensive profiling creates new surveillance and study possibilities and could inform new physical activity guidelines. Data are presented in various formats to demonstrate the dangers of misinterpretation when monitoring population adherence to Canada's Physical Activity Guidelines. Recommendations for physical activity and sedentary profiling are provided and future research needs identified.

Study Three

Purpose: This study explored the influence of modernity on the physical activity behaviours (e.g. intensity and timing) of children. **Methods:** Children aged 8-13 years living a traditional lifestyle (Old Order Amish; OOA n=68, Old Order Mennonite; OOM n=120) were compared with children living a contemporary lifestyle (rural Saskatchewan; RSK n=132 and urban Saskatchewan; USK n=93). Physical activity was objectively assessed for seven consecutive days using Actigraph 7164 accelerometers. Custom software was used to reduce the raw accelerometer data into standardized outcome variables. **Results:** On weekdays there were group differences in moderate physical activity between all lifestyle groups (OOA > OOM > USK > RSK). On the weekend, the group differences in moderate physical activity persisted between, but not within, lifestyle groups (OOA = OOM > USK = RSK). During school hours, all groups had similar activity and sedentary timings; however, they differed in magnitude with the OOA and OOM being both more sedentary and more active. Compared to in school, the

OOA and OOM children had 44% lower sedentary time out of school compared to only 15% lower for RSK and USK children. **Conclusions:** Though cross-sectional, these data suggest that contemporary/modern living is associated with lower levels of moderate and vigorous intensity physical activity compared to lifestyles representative of earlier generations. Analyzing the physical activity and sedentary patterns of traditional lifestyle groups such as the OOA and OOM can provide valuable insight into the quantity and quality of physical activity necessary to promote health.

General Conclusions: Together, these three studies will help contribute to the generation of best practices in the accelerometric profiling of both physical activity and sedentary behaviours.

Acknowledgements

I would like to begin by acknowledging the support, invaluable advice, and kindness of my supervisor, Dr. Adam Baxter-Jones. Thanks must also go to Dr. Mark Tremblay for seeing something in me that deserved a chance at higher learning and for inspiring in me a thirst for academic discovery. I would also like to thank my committee members, Dr. Gord Binsted, Dr. Jon Farthing, and Dr. Nazeem Muhajarine for their expertise in their respective disciplines. Special mention must also be made of Eric Finley's tireless contributions to my data analysis programs and to Dr. Jennifer Copeland, Joel Barnes, Dr. Trudy Huntington, and Dr. David Bassett for their dedication to the Amish and Mennonite research. Thanks are also extended to all of the children and research assistants who donated their precious time to this research. Lastly, I would like to acknowledge the National Science and Engineering Research Council (NSERC) and the College of Kinesiology for the funding support I received throughout my Ph.D. program.

D.W.E

Dedication

This work is dedicated to my family who have had to put up with my "meandering approach" to completing my PhD. You may not know it, but trust me when I say that I called upon each of you countless times to get me through this work. To Lauren, Mom and Dad, and my brother Keith, thanks for all your love and support and patience, your example of hard work and determination was and always will be contagious. Thanks to my wonderful children, Olivia, Jack, and Georgia, for making every day an absolute pleasure.

D.W.E

Table of Contents

List of Tables

List of Figures

List of Abbreviations

A/D	Analog to digital converter
ADP	Adenosine Diphosphate
ANOVA	Analysis of variance
ATP	Adenosine Triphosphate
Avg	Average
BMI	Body Mass Index
BMR	Basal metabolic rate
CHMS	Canadian Health Measures Survey
CDC	Centers for Disease Control
cm	Centimetre
cm^2	Centimetres squared
CTS	Counts
CV	Coefficient of variation
CV_{intra}	Intra-instrument coefficient of variation
CV_{inter}	Inter-instrument coefficient of variation
DLW	Doubly labelled water
DST	Daylight Saving Time
ECG	Electrocardiograph
EE	Energy Expenditure
g	Gravitational constant; where 1 g equals 9.81 $m \cdot s^{-2}$ at sea level
g-force	gravitational force
GPS	Global Positioning System

ΔG	Gibbs free energy
hr	hour
HR	Heart rate
Hz	Hertz
ICC	Intraclass correlation coefficient
IDEEA	Intelligent Device for Energy Expenditure Assessment
IOM	Institute of Medicine
kcal	Kilocalorie
KHz	Kilohertz
kJ	Kilojoule
m	Metre
MANCOVA	Multivariate Analysis of Covariance
MEMS	Microelectromechanical systems
METS	Metabolic equivalents
mph	Miles per hour
$m \cdot s^{-2}$	Metres per second squared
$mV \cdot g^{-1}$	Millivolts per g
MVPA	Moderate-to-vigorous physical activity
mm	Millimetre
mol	Mole
MSSE	Medicine & Science in Sports & Exercise
n	Sample size
NEAT	Non-exercise activity thermogenesis

NHANES	National Health and Nutrition Examination Survey
NHLBI	National Heart Lung and Blood Institute
NIH	National Institutes of Health
OOA	Old Order Amish
OOM	Old Order Mennonite
P	P-value; also known as alpha level
PA	Physical activity
PACY	Physical Activity of Children and Youth Study
PAEE	Physical activity energy expenditure
PAQ-C	Physical Activity Questionnaire for Children
PAR	Physical activity ratio
PAR-Q	Physical Activity Readiness Questionnaire
PC	Personal computer
Pi	Inorganic phosphate
$rad \cdot s^{-1}$	Radians per second
$rev \cdot m^{-1}$	revolutions per minute
ROC	Receiver Operator Characteristics Curves
RMR	Resting metabolic rate
RQ	Respiratory quotient
RQES	Research Quarterly for Exercise and Sport
RSK	Rural Saskatchewan children
SD	Standard deviation
SEM	Standard Error of the Mean

SI International System of Units

SR Quest Self report questionnaire

TEE Total energy expenditure

USK Urban Saskatchewan children

$\dot{V}CO_2$ Carbon dioxide production per minute

$\dot{V}O_2$ Oxygen uptake per minute

work·kg^{-1} Work per kilogram

$\overline{X}$ Symbol for mean

Chapter 1: Introduction and review of literature

1.1 Introduction

Physical activity plays in important role in the aetiology of over 35 chronic diseases and disorders, the most alarming of which is the epidemic rise in the prevalence of obesity and type 2 diabetes in the developed world (Booth et al. 2002; Chakravarthy and Booth 2004). Accurate measurements of physical activity are crucial to our understanding of the activity–health relationship, estimating population prevalence, identifying correlates, detecting trends, and evaluating the efficacy of interventions (Dollman et al. 2008b). Unfortunately, the exposure assessments in physical activity epidemiology are often crude which can contribute to inconsistent results among studies (Lagerros 2009; Lagerros and Lagiou 2007b). Traditionally, epidemiologists have relied on the assumption that the use of simple exposure measures lead to an underestimation of the true exposure-health relationship; however, physical activity is doubly complex because it can be both over and under reported (Welk et al. 2002). Unfortunately, most large studies of physical activity, including most national population surveillance programs, rely almost exclusively on "simple" exposure measures such as those obtained from physical activity questionnaires (Katzmarzyk and Tremblay 2007). Although questionnaires have been sufficient to demonstrate crude associations with disease end-points, uncertainties exist about the subjective nature of the data, which dimension of physical activity is being assessed, and the degree to which the assessment is valid (Adams et al. 2005; Rennie and Wareham 1998; Sallis and Saelens 2000; Schmidt et al. 2008; Shephard 2003; Wareham and Rennie 1998). As a result, the exact quantity, quality, and type of physical activity required to establish health protection remains unclear. Such clarity can only be achieved with reliable and valid measurement instruments.

Choosing the most appropriate instrument(s) to measure physical activity in a particular study depends on a number of factors, including the main dimension(s) of physical activity that is of health interest, the size of the study, and the frame of reference (e.g., current activity or past activity) (Rennie and Wareham 1998). A vast array of possible field methods exist and the relative merits of each have been well described previously (Montoye et al. 1996; Welk 2002). Recent advances in low power, low cost, microelectromechanical systems (MEMS) has lead to an increase in sensor-bases activity monitoring technologies such as pedometers, inclinometers, and accelerometers to name a few (Chen and Bassett, Jr. 2005). However, over the past decade it has been accelerometers that have gained the favour of researchers. Fortunately, industry responded to this demand by turning out a number of different models and greatly increasing the functionality of these measurement tools (see Godfrey et al. (2008) for a comprehensive review). In fact, accelerometers are now one of the most commonly used tools for assessing free-living physical activity (Welk 2002) and are playing an increasing role in surveillance, observational, and intervention research. However, not long ago accelerometers were still being considered technologies that were in the developmental stage. For example in a 1999 Copper Institute hosted meeting titled "Measurement of Physical Activity", one of the conclusions was that objective sensors were not practical for large-scale studies because of the high cost, uncertain reliability, and difficulties in the interpretation of the data (Troiano 2005). However, less than five years later, in 2004 at a conference titled "Objective Measurement of Physical Activity: Closing the Gaps in the Science of Accelerometry", use of accelerometry was overwhelmingly supported as "ready for prime time". Although the 60 invited scientists, the present author among them, endorsed the use of accelerometers for measuring physical activity, consensus could not be reached on decisions related to data analysis nor could agreement on cut points for the classification of physical activity intensity be reached (Troiano 2005).

Five years later, in 2009, the American College of Sports Medicine was one of a quartet of organizations, among them, the National Cancer Institute, the National Heart, Lung, and Blood Institute, and the National Institute of Environmental Health Sciences that co-sponsored a meeting titled *Objective Measurement of Physical Activity Conference: Best Practices and Future Directions*. The aim of the conference was to identify the “what” and the “how” of objective monitoring of physical activity. Organizers wished to tackle multiple issues, inter alia, the lack of a ‘Best Practice’ for: 1) determining which accelerometer to use for a given application, 2) accelerometric data reduction and the generation of outcome variables, and 3) profiling/interpreting physical activity and sedentary data. These issues are seen as the major hurdles in the evolution of the accelerometric measurement of physical activity.

Therefore, the purpose of this three study dissertation was to develop innovative methodologies in each of these above-mentioned areas in an effort to establish a solid foundation for the development of ‘Best Practice’ in these important areas of physical activity measurement.

Aims of Study 1

The purpose of Study One was to determine which of the three most commonly used accelerometer models Actical (Mini Mitter Co., Inc., Bend, OR), Actigraph model 7164 (Actigraph, Fort Walton Beach, FL), or RT3 (Stayhealthy, Inc., Monrovia, CA) has the best intra- and inter-instrument reliability, using a mechanical laboratory setup. Secondly, this study aimed to determine the individual and combined effects of acceleration and frequency of movement on accelerometer count output.

Aims of Study 2

Study Two is a review paper that explores the physical activity and sedentary behaviour profiles that can be acquired through objective monitoring, with a focus on accelerometry. Using previously collected objective data, a detailed physical activity profile is presented and case study examples of data utilization and interpretation are provided. The rich detail captured through comprehensive profiling creates new surveillance and study possibilities and could possibly inform new physical activity guidelines. Data are presented in various formats to demonstrate the dangers of misinterpretation when monitoring population adherence to Canada's physical activity guidelines. Recommendations for physical activity and sedentary profiling are provided and future research needs identified.

Aims and Hypotheses of Study 3

The purpose of Study Three was to profile the physical activity and sedentary behaviours of Old Order Amish (OOA), Old Order Mennonite (OOM), and contemporary-living children as a means of assessing the influence of lifestyle. Hypothesis 1 was that group differences in physical activity would be evident (i.e., Amish > Mennonite > contemporary-living children). Hypothesis 2 was that group differences in sedentary time would be evident (i.e., contemporary-living > Mennonite > Amish children). Hypothesis 3 was that the time of the day and the day of the week when most (majority) of the physical activity occurring in Amish and Mennonite children would be different from that occurring in the contemporary-living children.

1.2 Review of literature

1.2.1 Measurement

Galileo is often credited as the father of modern science as it was his 1610 dictum, "Count what can be counted, measure what is measureable and what is not measureable, make measurable", that initiated the transformation of science from that based on Aristotelian logic to that of empiricism (Ferris 2004). Up until the Renaissance, scientists were free to declare any logically founded physical statement and no experimental proof, no measurements were needed (Walcher 1988). In 1693 Decartes contributed to this paradigm shift (Kuhn 1996) in science by suggesting that the mind solves problems by breaking them down into successively smaller elements until they become understandable a paradigm that has become known as reductionism (Sydenham 2003).

Perhaps the most well known declaration on measurement was that made by William Thomson (Lord Kelvin). In 1883, during a lecture to the Institution of Civil Engineers, he stated

> ''In physical science a first essential step in the direction of learning any subject is to find principles of numerical reckoning and methods for practicably measuring some quality connected to it. I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind: it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of science, whatever the matter may be.''

However, the notion that to be valued, scientific data must be expressed objectively in the form of dimensional measurements is an misinterpretation of Kelvin's dictum (Sydenham 2003). Although the paradigm shifting dicta of these great thinkers ushered in an age of enlightenment for science, the over-zealousness of Kelvin's supporters led one prominent clinical epidemiologist to declare "the curse of Kelvin" (Feinstein 1971). Feinstein reminds us that Kelvin, a physicist, was addressing engineers when he made that statement and goes on to warn against the unthinking and inappropriate worship of quantifiable information in medicine. This lamentation is shared by many fields of study as most seem easily seduced into accepting the objectivity of apparent quantification. One needs only read through the litany of scales created to assign numbers to the subjective to find evidence of this numerophilia (Seidel 1986). However, quantitative measures alone offer only a partial definition of phenomena. Quantification is a crucial limitation in the realm of social measurement because the complexity of most social interactions and change can rarely be understood purely in terms of quantifiable parameters (US General Accounting Office 1979).

Throughout his life, Kelvin (1824-1907) would have seen firsthand the strides made in the medical sciences as clinicians began to employ advanced measurement systems, complete with physical measurement tools, to assist in disease diagnoses, prognoses, and the development of therapeutic guidelines. Invented in 1816 and 1895 respectively, the stethoscope and the x-ray are cogent examples of this evolution as it allowed physicians to base their diagnoses on information/data obtained from mechanical/electrical instruments rather than solely on subjective, self-reported histories or visual inspection (Reiser 1979). The development and adoption of these new measurement tools/procedures ultimately lead to a paradigm shift in terms of the theory of disease.

Fortunately, the concept of measurement has evolved over time from being overly focused on quantification in and of itself, to a broader focus on the elicitation of information about the phenomena being measured and making that information meaningful and usable (Ferris 2004). The essentials of this form of measurement system require the answers to the following questions (Sydenham 1985):

i) What knowledge is sought?

ii) What measurands (i.e., particular quantity subject to measurement) need to be used?

iii) What should the performance specification of the measurands be?

iv) How are the resultant measured data to be used?

This concept of measurement is nicely laid out by Sydenham's (2003) continuum of intelligence (Figure 1.1). Unfortunately, the weakest step in the measurement process is the decision of what to measure. The sign hanging over Albert Einstein's office door at Princeton captures this sentiment particularly well, it reads: Not everything that counts can be counted, and not everything that can be counted counts. It is clear that the decision of what to measure (i.e., what data to collect) needs to be well informed in order to facilitate the task of translating data into much sought after knowledge and further up the taxonomy to wisdom. Indeed, this led one acclaimed futurist to say: "we are drowning in information, but we are starved for knowledge" (Naisbitt 1986). The fact is, most fields of study are inundated with data; however, the translation of those data into useful knowledge is severely undersubscribed (Larose 2005).

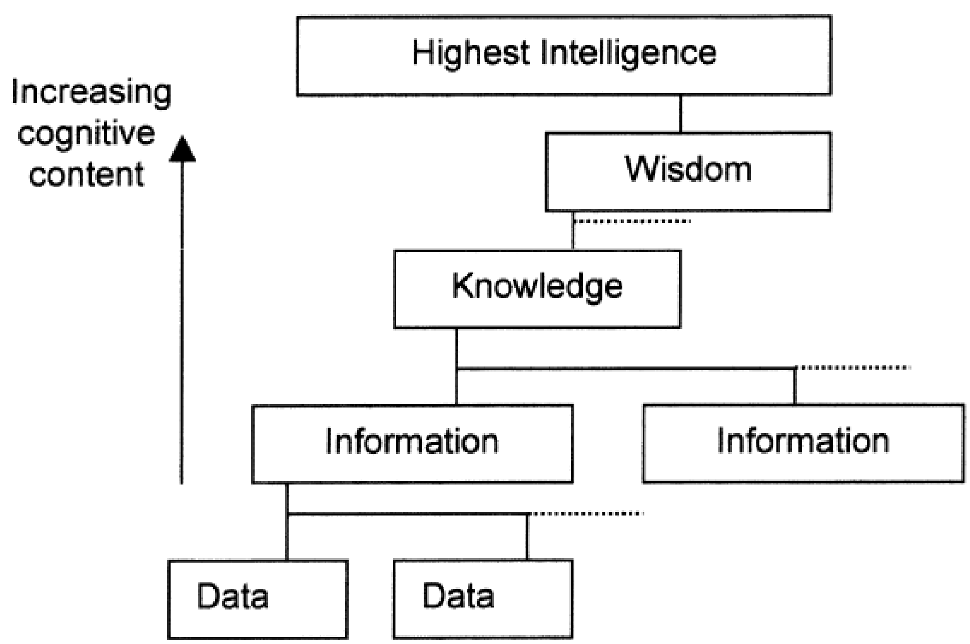


Figure 1.1. Schematic of a continuum of intelligence for a measurement system.
Note: As published in Sydenham (2003)

1.2.2 Definition of Physical Activity

In the field of physical activity, the decision of what to measure is made even more difficult because the exposure is complex and multidimensional (LaPorte et al. 1985) and researchers often use different terms to define the underlying dimensions. For example, exercise physiologists often define physical activity as "any bodily movement produced by skeletal muscles that results in caloric expenditure" (Caspersen 1989). However, others have suggested that physical activity involves a behavioural component implying that some level of voluntarism is involved (Freedson and Miller 2000). Others stress the importance of sub-dimensions of physical activity—frequency, intensity, duration, mode, and context (Haskell 2001; Kesaniemi et al. 2001; Montoye 2000). Frequency is defined as the number of bouts of activity per time period (e.g., day, week, month, etc.). Intensity is defined as the effort associated with the physical activity (e.g., light, moderate, vigorous) and is usually expressed in terms of energy expenditure. Duration refers to the time spent in physical activity (e.g., minutes, hours). Together, the product of frequency, intensity, and duration yield the volume of physical activity or dose. The mode of physical activity helps describe what type of activity is being performed (e.g., walking, running, swimming, gardening). Finally, the physical activity context refers to the practice of categorizing one's physical activity according to identifiable portions of daily life (e.g., leisure-time, occupational, transportation-related physical activity).

1.2.3 Measuring physical activity

In addition to understanding the sub-dimensions of physical activity, one must understand the relationship between physical activity the behaviour, and energy expenditure, the caloric cost of the behaviour (Figure 1.2). This is particularly important in terms of understanding the dose-response relationship between physical activity and health. The global construct representing the exposure variable within the activity-health paradigm is best defined as “movement,” with two dimensions: physical activity (the behaviour) and energy expenditure (the physiological response to the behaviour) (Lamonte and Ainsworth 2001). Regardless of the methods used to measure movement, some form of extrapolation to units of energy expenditure is necessary to assess the relationship between movement and health outcomes. The reason for this extrapolation is due to the fact that energy expenditure has been shown to relate better to health outcomes than specific forms of physical activity (Lee and Paffenbarger, Jr. 1998; Manson et al. 1999). Assessments of behaviour include among others, direct observation, physical activity diaries, recall questionnaires, pedometers, and accelerometers. Assessments of energy expenditure include among other methods, calorimetry, labelled isotope methods, and energy intake.

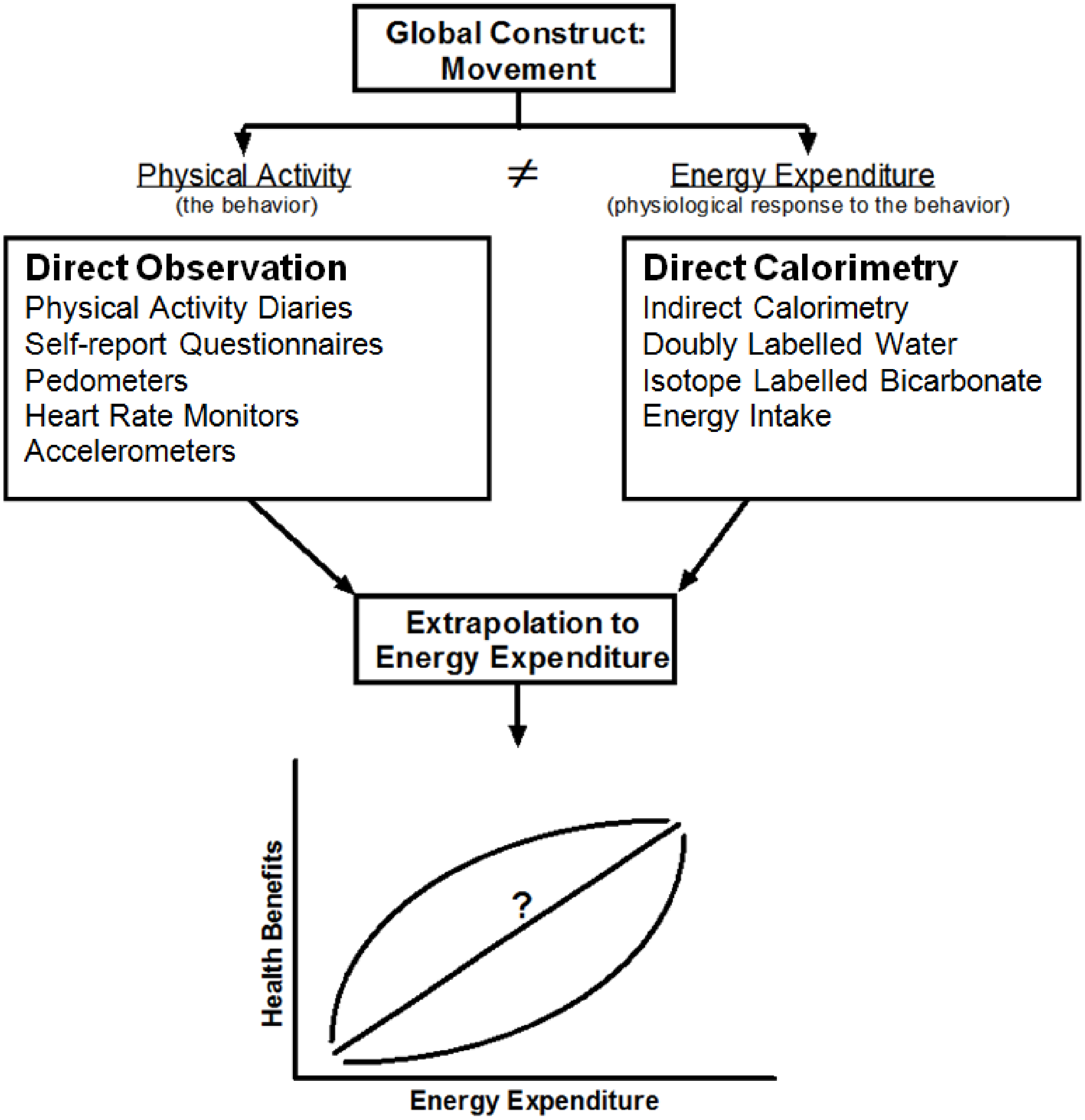


Figure 1.2. A conceptual model of the relationship between movement, physical activity, and energy expenditure, as well as various measurement methods (adapted from LaMonte and Ainsworth (2001)).

Each branch of the conceptual model in Figure 1.2 can be further sub-classified. The first entry in each listing has its font bolded to indicate that the direct measurement is different from the other methods in the list. More specifically, the items that follow the direct methods are designed to indirectly quantify the directly measured entity. However, there is another important distinction that must be made when measuring energy expenditure and it relates to which components of energy expenditure are included in any given measurement method. For example, Figure 1.3 highlights the fact that total daily energy expenditure (TEE) can be divided into 4 major components: 1) resting metabolic rate (RMR), 2) thermogenesis, 3) non-exercise activity thermogenesis (NEAT) which includes spontaneous forms of physical activity such as fidgeting and postural tone, and 4) exercise, the term used to define more purposeful physical activity (Ravussin 2005). These latter two categories are often combined under the umbrella term of physical activity energy expenditure (PAEE). RMR represents 50-70% of TEE, thermogenesis, which also includes the thermal effect of food digestion and accounts for 10% of TEE, where PAEE represents 20-40% of TEE and is the most variable or modifiable component.

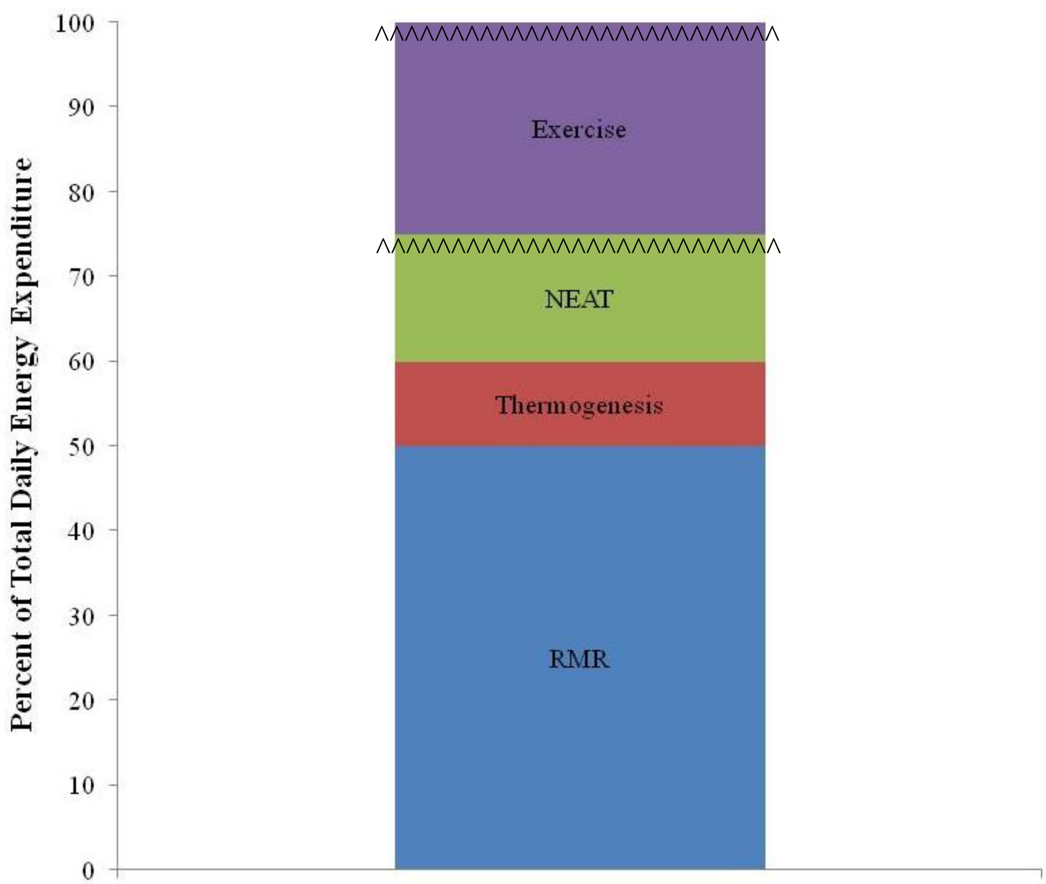


Figure 1.3. Schematic of the components of total daily energy expenditure
Note: saw tooth lines indicate highly modifiable components; adapted from Ravussin (2005)

The sections that follow provide a brief description of the various common methods of assessing physical activity and physical activity-derived energy expenditure. The section on accelerometry is, in comparison, much more detailed as it is fundamental to this dissertation research.

1.2.4 Direct Calorimetry

Calorimetry is term given to the measurement of heat production and can be conceptualized as belonging to one of two categories, direct, and indirect. Direct calorimetry, as the name suggests, measures heat output directly. In the nutritional sciences, a bomb calorimeter (see Figure 1.4) is used to assess the energy value of food. Bomb calorimeters operate on the principle of direct calorimetry, measuring the heat liberated as food burns entirely. Given that the first law of thermodynamics states that energy can neither be created nor destroyed but only converted from one form to another, the quantity of heat liberated is equal to the energy content in the macronutrients of the food. In the food industry, the favoured unit of measurement to express a given quantity of heat is a kilogram calorie or kilocalorie (kcal). A kilocalorie represents the amount of heat required to raise the temperature of 1 kg (1L) of water by 1 °*C*. The kilocalorie is a pre *International System of Units (SI)* unit and although its use is commonplace in the food and exercise science industries, the preferred scientific unit is the kilojoule (kJ); where 1 kcal = 4.184 kJ.

The same measurement principles of the bomb calorimeter can be applied to the study of human energy balance using direct calorimetry. The key principle behind direct calorimetry is that all of the body's metabolic processes ultimately result in heat production. For example, in cellular respiration, the chemical energy in food (i.e., carbohydrate, lipid, and protein molecules) is transferred to other activated molecules, most notably, Adenosine Triphosphate (ATP). The simple example outlined in equation 1.1 describes the energy liberating breakdown of one mole (180 grams) of glucose.

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + 36\ ATP + Heat \quad -\Delta G\ 686\ kcal \cdot mol^{-1} \qquad (1.1)$$

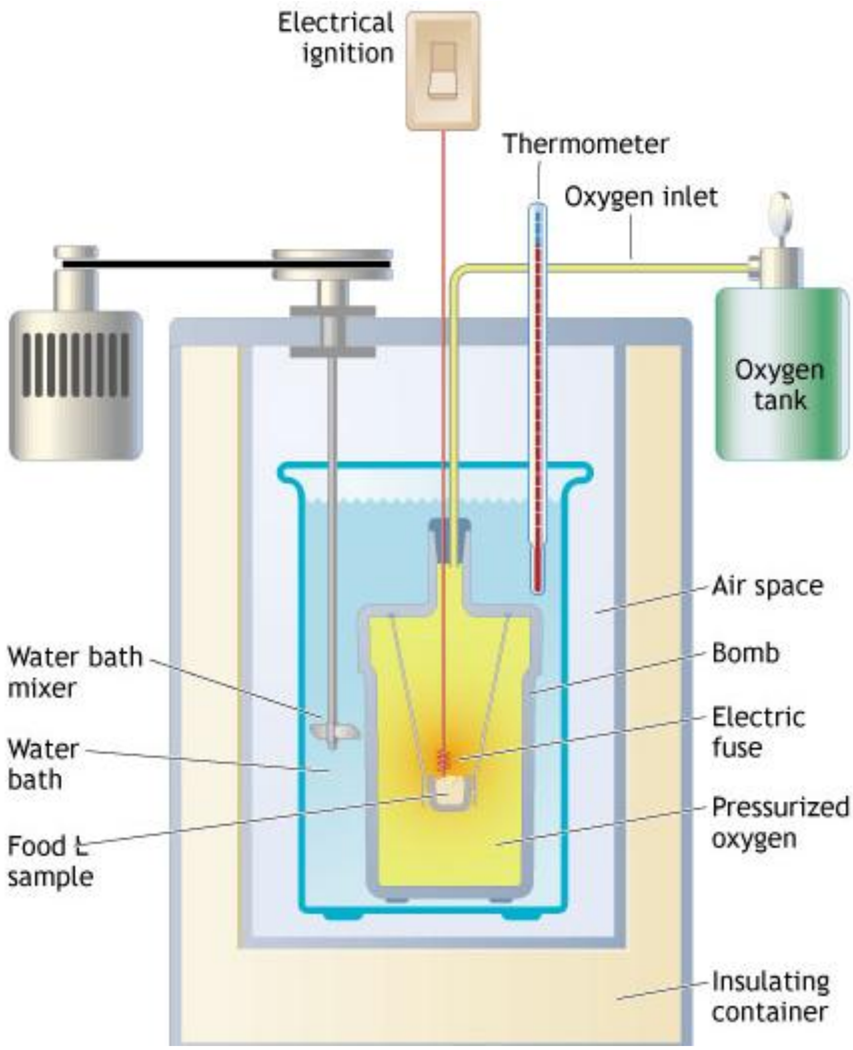


Figure 1.4. Schematic of a bomb calorimeter
Note: As published by McArdle et al. (2001b)

Often described as the energy currency of the body, ATP is the chemical storage form of energy that, when released (see equation 1.2), is harnessed to perform all biological work, from breathing and digestion to skeletal muscle contractions.

$$ATP + H_2O \rightarrow ADP + Pi \quad -\Delta G\ 7.3\ \text{kcal} \cdot \text{mol}^{-1} \tag{1.2}$$

However, unlike the bomb calorimeter, the human body is not an efficient machine as 62% of the energy required to metabolize glucose is liberated as heat, as a by-product. Fortunately, this heat can be measured and can be used as a method of measuring physical activity or more specifically, energy expenditure. Human heat production is measured via a direct calorimeter, a thermally-insulated chamber through which an absorbent medium is pumped via piping and/or ductwork (e.g., water or air) (see Figure 1.5). That is, the difference in temperature between the water entering and leaving the chamber directly reflects the human heat production. The sources of this heat are: radiation, convection, conduction, evaporation, work against external forces, and stored heat (Webb 1980).

In the seven year period from 1896-1902 Atwater and Benedict (1903) developed the method of direct calorimetry and in effect, verified the fact that the first law of thermodynamics was as applicable to live reactions in humans and animals as it was inanimate reactions. Their pioneering work also helped establish the validity of indirect calorimetry (described in detail in the next section). Though highly accurate (1%) and precise (2-3%), direct calorimetry is expensive, technically demanding and too restrictive to allow measurement of heat production in free-living environments (Schoeller and van Santen 1982). For these reasons, calorimetry is mainly used to validate other methods of assessing physical activity or to determine the energy costs of specific activities (Montoye et al. 1996).

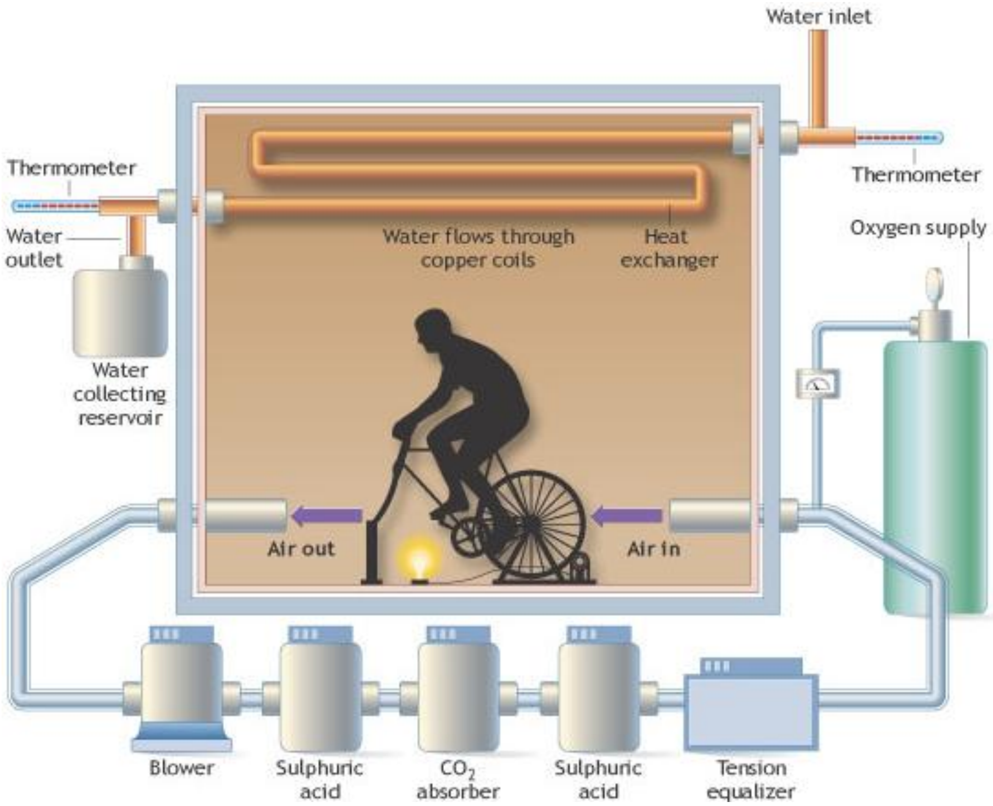


Figure 1.5. Schematic of the Atwater-Rosa calorimeter
Note: As published by McArdle et al. (2001a)

1.2.5 Indirect Calorimetry

Indirect calorimetry calculates heat production from the stoichiometry of substrate oxidation by measuring the gas exchange associated with the oxidation of energy substrates. Equation 1.1 shows that cellular respiration consumes oxygen and produces carbon dioxide and heat. It is therefore possible to indirectly determine human heat production by measuring oxygen consumption and carbon dioxide production. Although the majority of energy for muscle contraction is generated by cellular respiration in the mitochondria, gas exchange at the lungs provides a valid measure of tissue respiration during steady-state activities. Steady-state activities are those in which the rate of oxygen consumption is sufficient to meet the oxygen demands of the tissues and anaerobic metabolic pathways are not called upon. The energy expended during steady-state activities is readily determined because the consumption of one litre of oxygen yields approximately 5 kilocalories. The actual energy yield per litre of oxygen consumed varies with the macronutrient composition of the foodstuffs oxidized. By measuring the ratio of carbon dioxide produced to oxygen consumed (a metric called the respiratory quotient, RQ) one can determine the proportion of a given fuel source (i.e., fat, carbohydrate, protein) being oxidized. When fat is the sole source of energy (see equation 1.3), RQ is 0.70 and the energy yield is 4.68 kcal per litre of oxygen. When carbohydrate is oxidized exclusively (see equation 1.4), RQ is 1.00 and the energy yield is 5.06 kcal per litre of oxygen (Starling 2002). Because protein (i.e., nitrogen) contributes little to energy metabolism, it is often left unmeasured because the extra effort involved in quantifying urinary nitrogen is often not worth the less than one percent reduction in error. As a result, most metabolic equations assume a mixed fuel source with 40% carbohydrate and 60% fat is present which results in an RQ of 0.82 and equates to an energy yield of 4.825 kcal per litre of oxygen consumed. Therefore, the maximum error involved in the estimation of energy expenditure during steady-state oxygen consumption is approximately 4%, on average (McArdle et al. 2001a). However, by actually measuring RQ, the error can be reduced to less than 2% (Seale et al. 1990). In 1949 a Scottish physician and physiologist derived an equation (see equation 1.5) to calculate heat energy production from RQ and oxygen consumption (measured in litres per minute ($\dot{V}O_2$)) (Weir 1949).

$$C_{16}H_{32}O_2 + 23\ O_2 \rightarrow 16\ CO_2 + 16\ H_2O \qquad RQ = 16\ CO_2 / 23\ O_2 = 0.696 \tag{1.3}$$

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O \qquad RQ = 6\ CO_2 / 6\ O_2 = 1.00 \tag{1.4}$$

$$\text{kcal} \cdot \text{min}^{-1} = [\,(1.1 \cdot RQ) + 3.9] \cdot \dot{V}O_2 \qquad (1.5)$$

The original conceptualization of an indirect calorimeter was similar to that of a whole room calorimeter; however it was instead called a respiration chamber. By controlling and measuring the volume and composition of air flowing into and out of the respiration chamber oxygen consumption and carbon dioxide production could be quantified and thus energy expenditure calculated. Although respiration chambers are still in use today, modern metabolic systems permit the measurement of gas exchange outside the confines of the chamber via laboratory metabolic carts or in the field via portable systems which allows for measurements to take place in more free-living environments.

1.2.6 Doubly Labelled Water

Although direct and indirect calorimetry are often considered 'gold standard' measures of energy expenditure in the laboratory, the doubly labelled water (DLW) method has emerged as a viable criterion measure of total energy expenditure in the field. The basic premise of the technique is that a dose of water containing known concentrations of stable isotopes (often called tracers) of hydrogen (^2H) and oxygen (^{18}O) is ingested and allowed to equilibrate with total body water. Over time, labelled hydrogen, also known as deuterium, is expelled from the body as water (^2H_2O) in the form of urine, sweat, and expired water vapour. Concurrently, labelled oxygen is expelled from the body as water ($H_2{}^{18}O$) and as expired carbon dioxide ($C^{18}O_2$) produced by the carbonic anhydrase system. Therefore, metabolic carbon dioxide production ($\dot{V}CO_2$) can be calculated from the difference in elimination rates of the two isotopes because ^{18}O in expired carbon dioxide is in equilibrium with ^{18}O in body water (Lifson 1966). Oxygen uptake and total body energy expenditure are extrapolated from $\dot{V}CO_2$ and an estimate of the

RQ is obtained from published equations (Black et al. 1986). At the baseline assessment, high precision isotope-ratio mass spectrometers are used to measure naturally occurring ^{2}H and ^{18}O in urine or saliva before the dose of DLW is ingested. Thereafter, urine or saliva samples are analysed daily or after 7 and 14 days. The timing of the isotope measurements is key because if the period of observation is too long the concentration of the dosed isotope is too small relative to the naturally occurring isotopes and if the period of observation is too short, then the elimination curve cannot be accurately calculated.

The DLW method is safe, unobtrusive and much less likely to influence the behaviour of subjects than other methods of assessing physical activity. Compared to direct or indirect calorimetry, total energy expenditure is accurate within 1% to 3% and repeated measures vary by only 4% to 7% (Schoeller and van Santen 1982). However, the DLW method offers no information about the nature or temporality of the physical activity undertaken. Furthermore, TEE derived from the DLW method does not distinguish between the duration, frequency, or intensity of the physical activity (Lamonte and Ainsworth 2001), crucial variables for assessing the relationship between physical activity and health. The feasibility of this measurement technique for widespread use is constrained by the cost of labelled oxygen, the cost of isotope-ratio mass spectrometers, and by the availability of trained investigators (Montoye et al. 1996). As such, DLW is best applied as either a reference method for evaluating other field measures of physical activity or for testing hypotheses generated from population studies.

1.2.7 Isotope Labelled Bicarbonate

Another tracer technique, the isotope labelled bicarbonate (radioactive $NaH^{14}CO_3$) method is principally similar to DLW and has been used to measure free-living total daily energy expenditure over shorter observation periods (from hours to up to 5 days) than in studies of DLW (Elia et al. 1988; Gibney et al. 2003). A known quantity of tracer is infused at a constant rate and eventually diluted by the body's CO_2 pool. Labelled carbons are recovered from expired air, blood, urine, or saliva. Metabolic $\dot{V}CO_2$, is determined from an isotope dilution curve. Total energy expenditure is estimated from endogenous $\dot{V}CO_2$ production and standard published equations for estimating RQ. More recently, Raj and colleagues (2006) demonstrated the possibility of using stable isotope labelled bicarbonate ($NaH^{13}CO_3$) in addition to the ^{14}C labelled substrate. In a concurrent validity study, Gibney and colleagues (2003) showed that the labelled bicarbonate method was equally valid to that of indirect calorimetry (assessed by a whole room calorimeter) and DLW. As one might expect, the limitations of bicarbonate tracer methods are similar to those discussed for DLW.

1.2.8 Heart Rate Monitoring

Heart rate monitoring made its debut in the field of Sports Science in 1978 with the first commercial release of a portable heart rate monitor for exercise training (Laukkanen and Virtanen 1998). Although this new device, the first to depart from the electrocardiograph (ECG), Holter-style embodiment, was marketed to sport coaches, it did not take long for exercise scientists to recognize its utility for the measurement of physical activity. The ability to measure and store heart rate data minute-by-minute was a significant advancement over older heart rate accumulation methods. Temporal heart rate data provides rich profiling information on frequency, intensity, and duration of physical activity (see Figure 1.6). Obtaining measures of heart rate (e.g., beats per minute) provides direct temporal evidence of the physiological response attributable to physical activity (Armstrong 1998; Welk et al. 2000). Based on the assumption that a linear relationship exists between oxygen uptake ($\dot{V}O_2$) and heart rate (Wilmore and Haskell 1971) one can estimate physical activity energy expenditure. However, this method is plagued with high levels of individual variability, with errors in energy expenditure ranging from 20-50% (Livingstone et al. 1990). A large portion of the variability can be attributed to differences in age, gender, and fitness levels between individuals. However, if individual $\dot{V}O_2$–heart rate curves are incorporated via incremental exercise tests, the error in heart rate derived energy expenditure is greatly improved to 5-18% (Bradfield et al. 1970; Strath et al. 2000) and becomes comparable to estimates obtained by indirect calorimetry (Spurr et al. 1988) and the DLW method (Davidson et al. 1997).

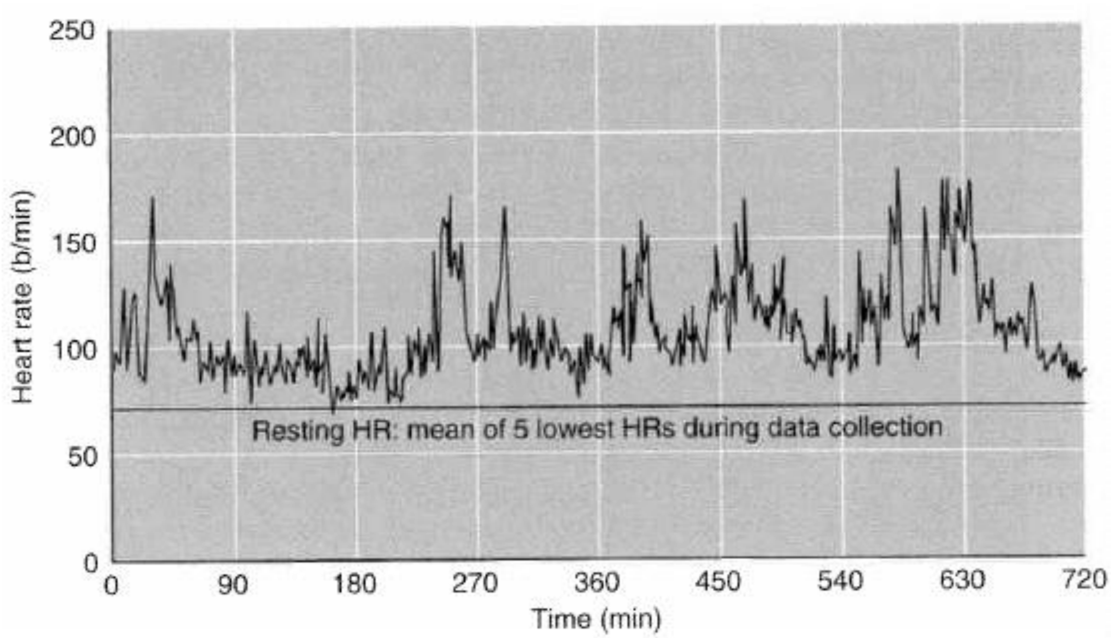


Figure 1.6. Twelve hour heart rate profile of a child from 8:00AM to 8:00PM
Note: As published by Janz (2002)

Further imprecision in the estimate of energy expenditure from heart rate can be attributed to attenuation in the $\dot{V}O_2$–heart rate relationship during low and very high intensity activities (Acheson et al. 1980). Other known confounders have been shown to skew heart rate while having minimal, and at times, variable impact on $\dot{V}O_2$ (e.g., body temperature, size of the active muscle mass (upper vs. lower body), type of exercise (static vs. Dynamic), stress, certain medications, fatigue, body position, hydration status, consumption of stimulants such as nicotine or caffeine) (Acheson et al. 1980; Livingstone 1997; Maas et al. 1989; Montoye et al. 1996; Montoye and Taylor 1984; Parker et al. 1989). Yet another challenge presented by heart rate monitoring is the fact that heart rate suffers from a temporal lag in response to the initiation or cessation of physical activity (Strath et al. 2000) making it more difficult to assess concurrent validity with other measurement methods.

1.2.8 Self-Report Questionnaires, Logs/Diaries, and Interviews

A seminal comprehensive review (LaPorte et al. 1985) concluded that self-report procedures provide the requisite combination of accuracy and practical application for assessing a population's physical activity levels. Therefore, it is not surprising that the most common method of measuring population-level physical activity is through self report measures, such as diaries/logs, surveys, interviews, or questionnaires (Adamo et al. 2009). These measures are popular due to their feasibility/practicality, low cost, low participant burden, and general acceptance (Dishman et al. 2001; Kohl et al. 2000). Physical activity diaries are often more accurate than recall surveys and recall questionnaires; however, diary completion is burdensome to participants; diary interpretation is burdensome to investigators; diary records may not reflect long-term physical activity patterns; and, diary use may alter one's physical activity habits by acting as a motivational tool (i.e., subject reactivity). Unlike diaries, recall surveys and recall questionnaires have no effect on behaviour and require relatively little effort by respondents.

Questionnaires can be self completed or interviewer administered and record information on the frequency, intensity, duration, and type of activities performed over a particular period of time. From these variables, estimates of the volume of activity-specific energy expenditure, expressed in metabolic equivalents (METS) or kilocalories can be calculated. Although self report questionnaires are useful for gaining insight into the physical activity levels of populations, they risk overestimating and/or underestimating true physical activity energy expenditure and sedentary behaviours (Adamo et al. 2009). That said, some global assessments administered by telephone, questionnaire, or interview seek only categorical information, such as participation in regular exercise or self-rating of physical activity relative to peers (Jacobs, Jr. et al. 1993). The Physical Activity Questionnaire for Children (PAQ-C) is an example of a self-administered, 7-day recall questionnaire that measures general moderate-to-vigorous physical activity levels during the school year. The PAQ-C is low cost, reliable and valid assessment of physical activity for children and its ease of administration make it feasible for large-scale studies. The questionnaire was used successfully in the University of Saskatchewan's longitudinal Pediatric Bone Mineral Accrual Study (Bailey et al. 1999) (see Appendix A for a copy of the full questionnaire, complete with scoring procedures).

The self report methods of recalling intensity, frequency and duration of bouts of activity are considered problematic in children who are less time conscious than adults and tend to engage in physical activity in intermittent or sporadic bouts with varied intensities rather than consistent patterns (Armstrong and Bray 1991; Bailey et al. 1995; Berman et al. 1998). Not only is reliability compromised by recall difficulties but also the validity of measures may be affected in children and adolescents who feel compelled to respond in a certain way (Jago et al. 2007a). Warnecke and colleagues (1997) attributed the over reporting of physical activity in these situations to what he called social desirability. It seems that society has come to know that being physically active, like eating a well balanced diet, is the socially desirable “thing to do”.

In fact, self report questionnaires possess several additional limitations in terms of their reliability and validity (Shephard 2003). The list below outlines some key examples of potential issues that may arise when different questionnaires are used or during repeat administrations of the same questionnaire over time:

- Differential interpretation and/or operationalization of the definitions of the terms 'exercise' and 'physical activity';
- Differing domains of physical activity (leisure-time, gardening/yard work, household chores, physical activity for transport, occupational physical activity);
- Differing time frames (e.g. last week or last month versus usual week or month);
- Seasonality of participation in physical activity and/or sedentary behaviour may vary, especially in more variable/extreme climates;
- The timing of surveys needs to be consistent for trend comparisons;
- Differing classes of activity (generic/global questions) versus questions asked about each specific activity;
- Differential interpretation of the use of symptoms of activity (sweating, breathlessness) versus examples of types of activity to illustrate questionnaire items; and
- The impact of different modes of questionnaire administration: telephone, interview, or self-completed questionnaire.

Research has indicated that certain populations such as children are less likely to make accurate self report assessments than adults (Going et al. 1999). Children are more likely to misinterpret questions posed to them creating possible content validity problems (Welk 2002). Difficulties also arise when attempting to translate activity information from self-reports to energy expenditure (Goran et al. 1998). A major improvement in questionnaire assessment of physical activity was the inclusion of household sources of activity, which can be the primary context for physical activity among some groups (e.g. stay at home parents, retirees, etc.). In addition, some types of questionnaires include sources of physical activity common among certain racial/ethnic groups. However, efforts to understand how various population subgroups interpret certain constructs used in physical activity questionnaires, such as leisure time activity or moderate physical activity, are limited. Additional research indicates that self report methods generally provide less accurate indications of activity than more objective methods, such as doubly labelled water, heart rate monitoring, pedometers and accelerometers, (Adamo et al. 2009; Janz et al. 1995).

1.3.0 Direct Observation Techniques

Direct observation techniques are used to study human behaviour in free-living environments and often provide information during specific windows of time. For a detailed description of the various methods available the reader is referred to McKenzie (2002). The main advantage of direct observation is that it enables researchers to accurately describe what is taking place in the physical activity environment, thus generating both qualitative and quantitative information. Direct observation systems are often developed for target populations in specific settings and include the following characteristics: a well defined observation strategy to sample activities per unit of time, a list of activity categories to code movement types, a list of associated variables that may influence behaviour (e.g., context, teacher behaviour, environmental settings), supplemental methods to record concurrent levels of energy expenditure, data entry procedures (e.g., pencil and paper, computer, palm pilot), and detailed scoring schemes used to summarize the data (Pettee et al. 2009). Direct observation is predominantly conducted in children because of their limited ability to accurately recall physical activity or properly complete records, logs, and questionnaires and typically takes place in the school or home setting.

The most obvious disadvantage of this technique is related to the expense (i.e., researcher burden) necessary for data collection and scoring (Montoye et al. 1996). In order to increase confidence that accurate data are collected (i.e., to ensure high between-observer and within-observer agreement), observers must go through considerable training and evaluation before and during data collection. Subject reactivity is another limitation of direct observation as the presence of the observer may disrupt or change regular physical activity patterns, decreasing the reliability and validity of the data. As a result of these limitations, direct observation is typically confined to studies that are smaller and conducted in distinct settings over a shorter period of time.

1.3.1 Pedometers

Evidence suggests that step-based ambulation accounts for the majority of physical activity energy expenditure (Bassett, Jr. et al. 2000) thus step counts provide an objective measure capturing a significant portion of daily physical activity. Therefore, capturing step counts in long-term population surveillance of physical activity may be warranted. The primary tool used for the measurement of step counts is the pedometer (Schneider et al. 2004). Pedometers are small match book sized, battery operated waist-, ankle-, or foot-worn sensors that in their simplest form use a horizontal, spring-suspended lever arm that oscillates during step impact to increment the step accumulator (Freedson and Miller 2000). The accumulated step total provides a volumetric index of physical activity; however, it suffers from a lack of temporality (i.e., bout durations or time of day). That said, pedometers can provide an indication of the distance walked, by multiplying the number of steps by stride length. However, variables such as walking speed, height, age, and gender affect stride length (Welk et al. 2000).

Although pedometers are reasonably accurate at counting steps, they cannot discriminate between steps accumulated in walking, running, or stair climbing and therefore compromise measures of physical activity intensity (Bassett, Jr. and Strath 2002). Furthermore, the devices are not sensitive to upper body movements or activity that does not require locomotion (Melanson, Jr. and Freedson 1996). Measurement accuracy also decreases at very slow or very fast walking speeds (Bassett, Jr. et al. 1996; Crouter et al. 2003; Le Masurier et al. 2004; Le Masurier and Tudor-Locke 2003; Tudor-Locke et al. 2002). The implication is that they will disproportionally effect populations with a shuffling sort of gait (e.g., the frail elderly) (Melanson et al. 2004; Wilcox et al. 2001). Although this problem has been readily identified, it is unlikely to be corrected as there is an inevitable sensitivity/specificity trade-off; the greater the sensitivity (i.e., ability to detect low step forces), the less specificity (i.e., ability to discriminate between actual stepping movements and non-ambulatory oscillations of one's center of gravity such a changes in posture or mechanical vibrations caused by motor vehicle travel).

Research indicates that pedometers can offer distinct advantages over self-report methods as a form of physical activity monitoring. For example, physical activity questionnaires typically ask individuals to recall the distance that they walk on a daily basis (Ainsworth et al. 1993b). Individuals often have trouble remembering or may lack perception of distance and therefore provide inaccurate reports of the distance actually walked on a daily basis (Welk 2002). Research also reflects that it is often more difficult for individuals to accurately recall common, moderate-intensity activities such as walking than structured, vigorous exercise (Richardson et al. 2001).

In an effort to provide information on activity intensity some pedometer manufacturers have developed models that measure time-stamped step counts (e.g., Lifecorder EX, New Lifestyles). These new generation digital pedometers use steps accumulated per unit time to estimate intensity level. A better solution for those that require both the rich outcome variables provided by an accelerometer (Esliger et al. 2005) as well as the simple step count provided by a pedometer is to use a dual mode accelerometer. For example, the Actigraph (Fort Walton Beach, FL) has an auxiliary function that provides simultaneous, time-stamped measurement of both accelerometer counts and step counts.

2.1.7. Accelerometers

Accelerometry-based physical activity monitors are one of the most commonly used devices for assessing free-living physical activity (Welk 2002). In fact, the use of accelerometers in large-scale surveillance studies is on the rise (e.g., National Health and Nutrition Examination Survey (Troiano et al. 2008), Canadian Health Measures Survey (Tremblay and Gorber 2007), the Health Survey for England (Craig et al. 2009) and population level data from Sweden (Hagstromer et al. 2010)). Over the past decade accelerometers have become increasingly popular for assessing physical activity/sedentary behaviour. As a result, commercial suppliers have responded by producing a number of different models and greatly increasing the functionality of these measurement tools (see Godfrey (2008) for a comprehensive review). Although the technological evolution of the field has been beneficial, it has made it more difficult for end users to choose the best accelerometer model for their purposes. Unfortunately the notion of a “one size fits all” accelerometer is highly unlikely because monitor selection depends on the application for which it is intended (Bassett, Jr. 2000).

Described often as small pager-sized electronic measurement devices, accelerometers are worn on the waist, hip, wrist, and/or ankle. There are a variety of commercially available accelerometers and although there is a wide range in size, shape, and price, there is little variation in their basic functioning. Most MEMS accelerometers use some form of piezoelectric or piezoresistive technology to measure the intensity of body or body segment accelerations (see Figure 1.7). The basic premise of this approach was described by Cavagna and Margaria (1966) and is based on the idea of kinetic and potential energy of one's center of mass. Work is calculated in this method using the following equation:

$$\text{Work} = \text{kinetic energy}_{final} - \text{kinetic energy}_{original} = \tfrac{1}{2}\,\text{mass}\cdot\text{velocity}_{final}^{2} - \tfrac{1}{2}\,\text{mass}\cdot\text{velocity}_{original}^{2} \quad (1.6)$$

This model may be over simplistic as it assumes that changes in the body's center of mass reflects the energy changes in all body segments. This model also fails to account for energy losses due to the simultaneous generation and absorption of energy at different joints and many of the reciprocal or compensatory movements common in locomotor activities. Despite these limitations the center of mass approach to work or energy calculation is meritorious.

When accelerated, the piezosensor emits a voltage signal proportional to the intensity of the acceleration (see Figure 1.8). Various low and high pass frequency filtering techniques (see Figure 1.9) are employed to exclude accelerations unlikely to be generated by human movement. Human generated accelerations range from approximately 0-60 m/s^2 with a frequency response typically less than 10 Hz (Welk 2002) (see Figure 1.10). The capability of these devices, in terms of measuring accelerations in various planes, is dependent on the configuration and orientation of the piezosensor(s). At present there are uniaxial, bidirectional, omnidirectional, and triaxial accelerometers available for commercial purchase. Most manufacturers convert the raw acceleration data into some form of activity count over a user-defined interval from one second to several minutes or more (i.e., epoch) (see Figure 1.11). These activity counts provide an objective assessment of movement intensity, with greater accelerations producing greater counts. However, because counts are tallied in proprietary, manufacturer-specific units, they only allow the comparison of data among similar accelerometer models**.**

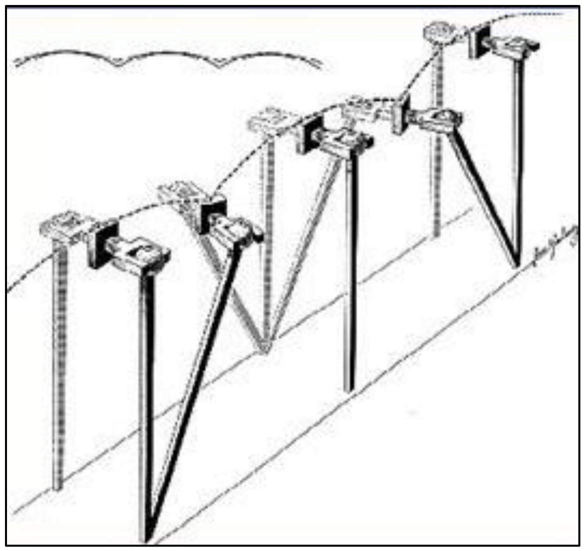


Figure 1.7. Conceptual illustration of movement (i.e., the rise and fall of the center of gravity) that occurs during ambulation using a simple stick model
Note: The basic premise of accelerometry is that a linear relationship exists between the integral of the modulus of body acceleration and energy expenditure for that activity.

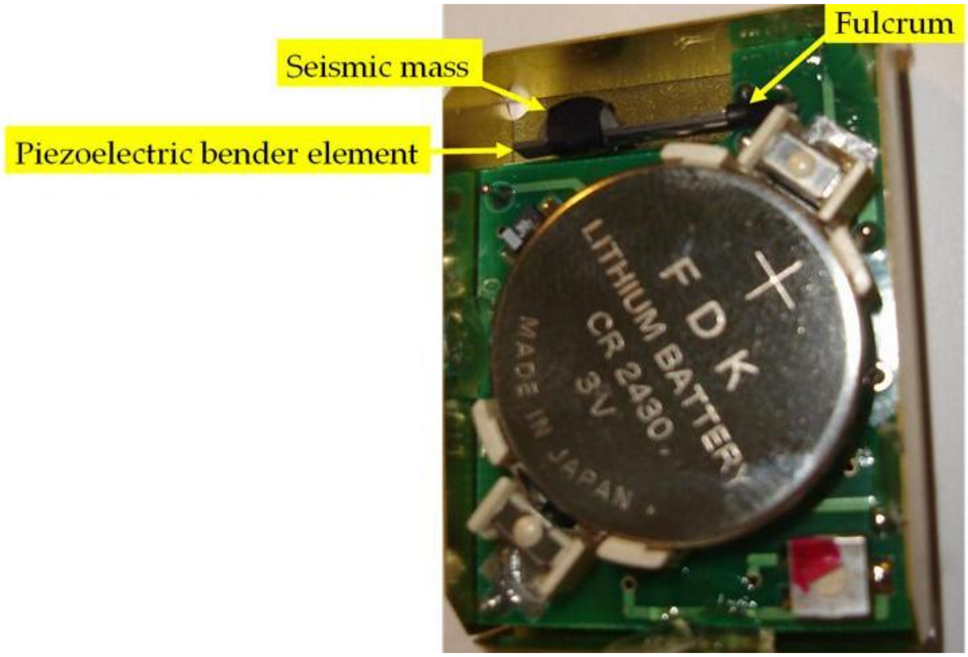


Figure 1.8. Internal components of a MEMS uniaxial accelerometer (Actigraph 7164; Actigraph LLC, Pensacola Florida)

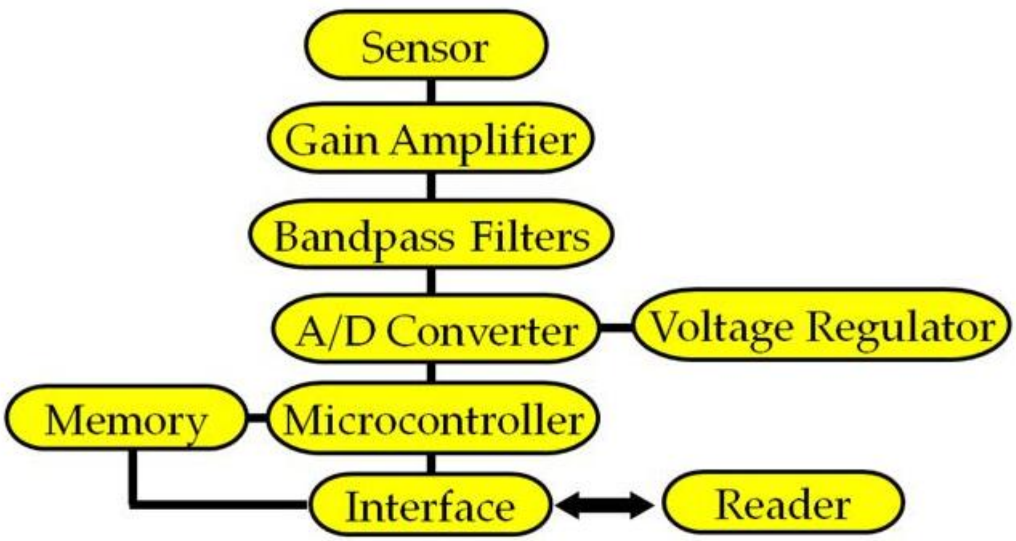


Figure 1.9. Typical MEMS accelerometer sensor design schematic
Note: Figure adapted from Tryon and Williams (1996).

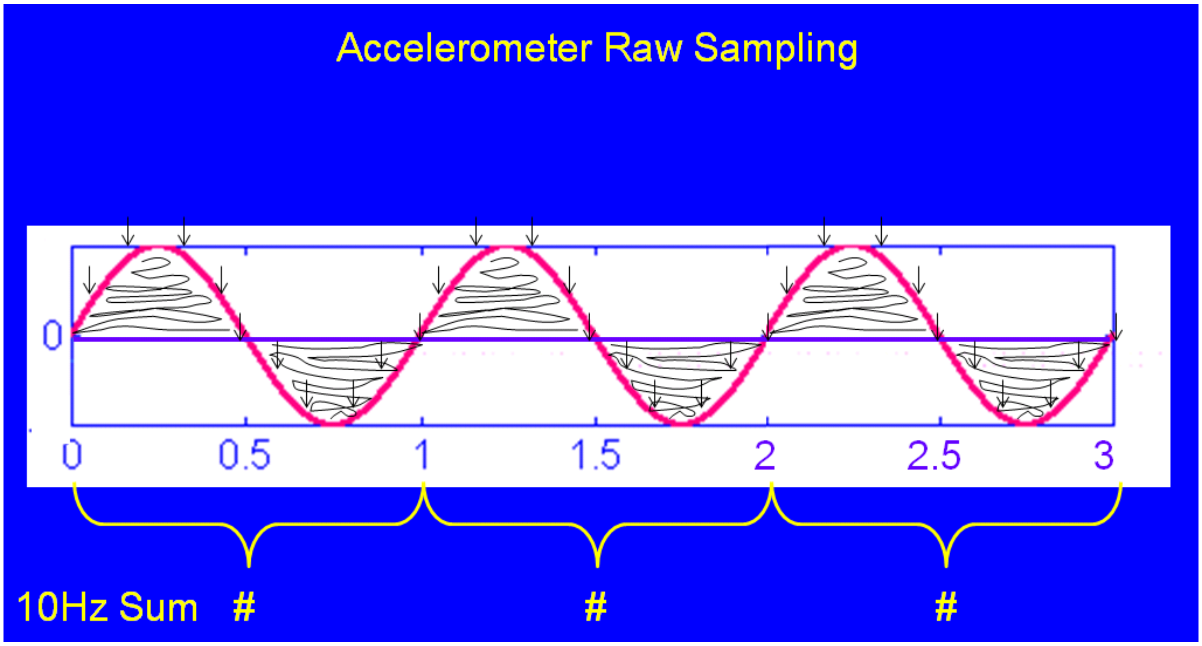


Figure 1.10. Illustration of the raw sampling procedure of a typical accelerometer
Note: The y-axis represents the magnitude of the acceleration signal; the x-axis is partitioned into 0.5 second increments; the arrows indicate the 10 Hz samples; the shaded area under the curve represents the integral of body acceleration; each 10 Hz sum represents 1 second of raw data in a unit called accelerometer counts.

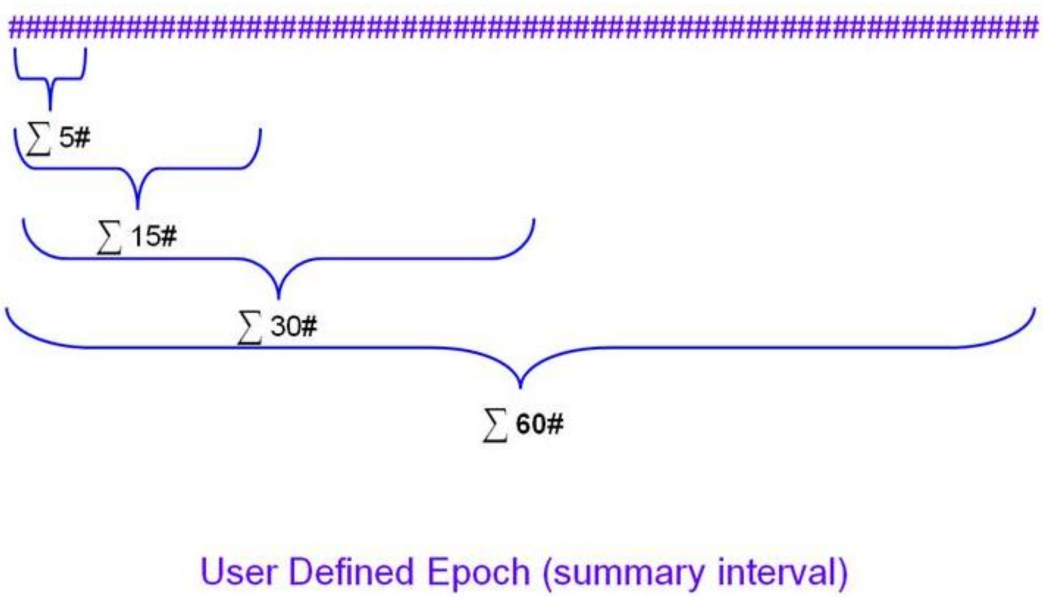


Figure 1.11. Conceptualization of how a user can define the summary epoch level to suit their needs in terms of the resolution of the acceleration signal (i.e., counts)
Note: The # symbols represent the 60 x 1 second raw data points; the summation symbols depict common summary epoch choices.

In practice, most users convert or ‘calibrate’ the count data into more physiologically relevant units, usually based on energy expended per unit time. For adults, light, moderate and vigorous intensity levels have been defined conventionally using the thresholds of 3 and 6 METS. For children and adolescents, there is no consensus as some use 3 and 6 MET thresholds, while others use 4 and 7 MET thresholds. To date, the most popular method used to calibrate accelerometer count data into time spent in physical activity is some form of count to intensity (i.e., energy expenditure) prediction equation is often used to generate intensity cut-points (see Figure 1.12).

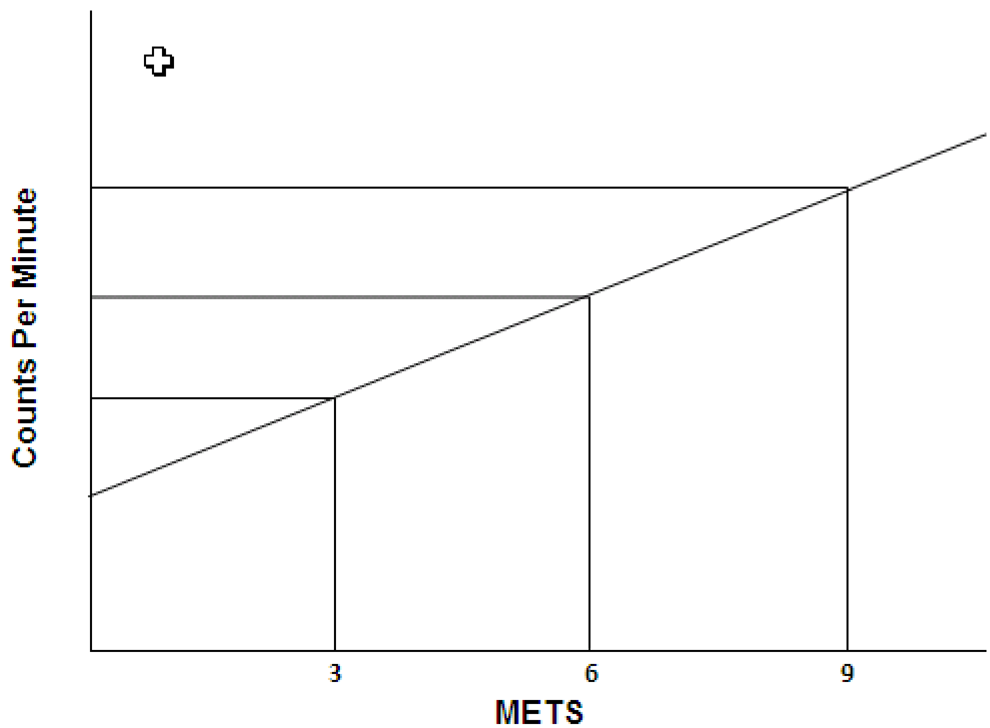
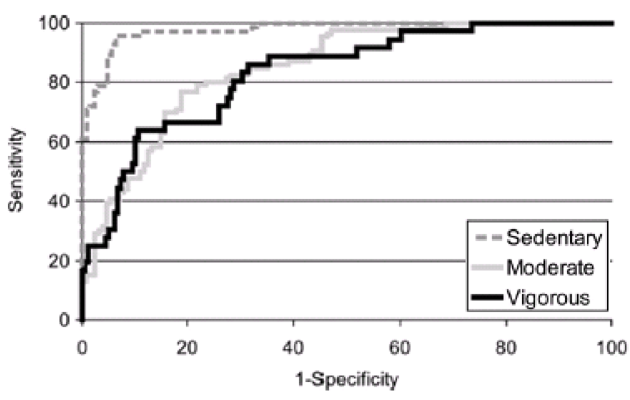


Figure 1.12. Conceptual illustration of an accelerometer value calibration study
Notes: i) The perpendicular lines represent the delineation of accelerometer counts per minute that correspond to a given intensity of physical activity (e.g., Moderate > 3 METS, Hard > 6 METS, Very Hard > 9 METS). ii) Figure inspired by Freedson and colleagues (1998).

Accelerometer cut-points have also been derived statistically using Receiver Operator Characteristics Curves (ROC). ROC curve analysis is a graphical technique for describing and comparing the accuracy of diagnostic tests. In accelerometry applications, ROC curve analysis is used to examine the potential of using count cut-points within a given accelerometer to discriminate between different activity intensity categories. As Jago et al. (2007b) described, ROC analysis is a means to evaluate and visualize the sensitivity [true positives/(true positives + false negatives)] and specificity [true negatives/(true negatives + false positives)] of tests. The ROC curve is simply a plot of the sensitivity of a test on the y-axis versus its 1-specificity (i.e. false positive fraction on the x-axis). Each possible threshold value corresponds to a point on the ROC curve. The upper-left corner [the point (0, 1)] represents perfect classification, and the diagonal line represents the strategy of randomly guessing. Sensitivity is maximized by correctly identifying at or above the threshold for intensity, whereas specificity is maximized by correctly excluding activities below the threshold for intensity. Therefore, the strength of ROC curve analysis is that the cut-points can be chosen to optimize the balance between sensitivity and specificity (i.e., point nearest 0,1 on the ROC curve) (see Figure 1.13 for an example).



	Sensitivity (%)	Specificity (%)	Area under the ROC curve (95% CI)	Count 15 s^{-1}
ActiGraph				
Sedentary	95	93	0.98 (0.95–0.99)	0–25
Light	NA	NA	NA	26–573
Moderate	77	81	0.85 (0.80–0.90)	574–1002
Vigorous	68	89	0.83 (0.78–0.88)	≥1003

Figure 1.13. Sample ROC curve analysis of children's accelerometer cut-points complete with diagnostic accuracy measures
Notes: i) NA, not applicable using ROC curve analysis; ii) intensity cut-points listed were chosen to maximize sensitivity and specificity; adapted from Evenson et al. (2008).

ROC curve analysis is known to be superior to previous accelerometer calibration methods that employed linear regression approaches (see Jago et al. (2007b) for a more thorough discussion on this topic). To date, only four studies have employed ROC curve analysis to generate cut points, and these were done on children (Chu et al. 2007; Evenson et al. 2008; Jago et al. 2007b; Welk et al. 2007).

For those involved in the use of accelerometers or for those dealing with accelerometric data (i.e., raw data and/or data that is published in manuscript formant) must understand that the interpretations of these data are severely complicated by the availability of several differing cut-point ranges which yield markedly different results for the same data (Strath et al. 2003). A discussion of appropriate cut-points is beyond the scope of this dissertation; however the lack of consensus, both within and between accelerometer models, remains a major barrier to data interpretation (Ward et al. 2005). Despite their limitations, accelerometer value calibrations are important in delineating the number of accelerometer counts per epoch corresponding to a given category of physical activity (e.g., light, moderate, vigorous). This allows an easy calculation of the time spent on physical activity, cited as one of the most relevant variables for population health research because of its direct link to current physical activity recommendations (Welk 2002). In fact, data mining of time in intensity levels can yield a comprehensive list of outcome variables detailing the frequency, intensity, and duration of physical activity and sedentary time that together provide a detailed profile of overall behaviour (Esliger et al. 2005) (see Figure 1.14).

While developed primarily for assessing movement, there has been considerable interest in using accelerometers to also indicate levels of sedentary behaviour (Healy et al. 2008b; Matthews et al. 2008; Pate et al. 2008). Sedentary thresholds have been determined arbitrarily, by observation, statistically, or physiologically as MET values less than 1.5. In addition, recent evidence suggests the amount of time spent in sedentary or light activity is related to clustered metabolic risk, independent of moderate to vigorous physical activity (Healy et al. 2008b; Healy et al. 2007). Clustered metabolic risk is simply the notion that metabolic risk factors tend to occur simultaneously more frequently than expected by chance alone (Andersen et al. 2003; Pahkala et al. 2010). This has lead to the acknowledgement that light and sedentary behaviours require equally accurate measurement tools as those used for more intense physical activity.

9:00 AM	0		
9:01 AM	0		
9:02 AM	0		
9:03 AM	0		
9:04 AM	0		
9:05 AM	0		
9:06 AM	0		
9:07 AM	0		
9:08 AM	0		
9:09 AM	0		
9:10 AM	0		
9:11 AM	0	Monitor On	
9:12 AM	397		
9:13 AM	290		
9:14 AM	221		
9:15 AM	279		
9:16 AM	919		
9:17 AM	96		
9:18 AM	33		
9:19 AM	187	Light	8
9:20 AM	1976	Moderate	1
9:21 AM	1016		
9:22 AM	886		
9:23 AM	109		
9:24 AM	0		
9:25 AM	0		
9:26 AM	0		
9:27 AM	84		
9:28 AM	384		
9:29 AM	815		
9:30 AM	1127	Light	10
9:31 AM	4126		
9:32 AM	4534		
9:33 AM	4773	Moderate	3
9:34 AM	7190		
9:35 AM	6891		
9:36 AM	6093		
9:37 AM	7226		
9:38 AM	7186	Hard	5

Category	MET Value	Counts
Light	≤ 2.99	≤ 1952
Moderate	3.0 to 5.99	1953 to 5724
Hard	6.0 to 8.99	5725 to 9498
Very Hard	≥ 9.0	≥ 9499

Figure 1.14. Tabular minute-by-minute accelerometer data complete with intensity categorization via the inlaid calibration chart.
Note: As published by Freedson and colleagues (1998).

Validity studies in adults have yielded moderate-to-strong correlations (r=0.45 to 0.93) between accelerometer counts and VO_2, PAEE or METS in adults and similar correlations (r=0.53 to 0.92) in children (Trost et al. 2005). Compared to uniaxial sensors, triaxial accelerometers theoretically provide a more comprehensive assessment of body movements; triaxial accelerometers have been shown to have higher correlations with measured energy expenditure in adults and children than uniaxial accelerometers in some but not all studies (Chen and Bassett, Jr. 2005; Van Hees et al. 2009; Westerterp 2009).

Muscle activity in walking and running serves two major purposes: to support body weight and to generate a propulsive impulse. Because the magnitude of the vertical component of ground reaction force is much greater than the forward and backward component, most of the metabolic energy during running comes from supporting body weight. The fact the vertical motion of the center of mass accounts for more energy expenditure than motion in the other two axes brings into question the need for triaxial accelerometers over uniaxial accelerometers. Triaxial accelerometry provides a technique for quantifying movement patterns during walking (Kavanagh et al. 2006; Kavanagh and Menz 2008). Normal walking patterns can be deduced from vertical and anterior-posterior accelerations, which coincide with step frequency and account for majority of the total signal power in each direction. Mediolateral accelerations are governed by the stride frequency. Specific gait-related movement can be measured from hip, shoulder, upper trunk, thigh and lower trunk accelerations. However, one particularly positive feature of triaxial accelerometers is that the validity and reliability of measurement is not as affected by improper physical orientation (aligned to the appropriate axis), because of body size or shape, clothing peculiarities or improper instruction. This concern is overcome by using the vector magnitude setting that combines the output from the x, y, and z axes into and overall count value.

This discussion on the relation of biomechanical factors on accelerometer-measured physical activity should highlight the importance of understanding the “black box”. Understanding the sources of error and reliability of accelerometers is essential because this ultimately sets the limit on the validity of these devices. Studies that aim to assess accelerometer reliability need to ensure that the source of movement is highly controlled so that nearly all variability can be attributed to the device (Tryon and Williams 1996). This can only be accomplished under laboratory conditions; however clinical or field repeatability is also important. Field reliability pertains to the conditions under which replicable activity measures can be obtained from subjects despite all the sources of variation that require instrument reliability and validity to be evaluated in the laboratory (Tryon and Williams 1996). Between-day stability is increased with the number of days assessed. Research suggests that 4-7 days of monitoring of people living under normal conditions are required to obtain a reliable assessment of physical activity behaviour (Janz et al. 1995; Trost et al. 2000).

Expectations that correlation coefficients may approach 1.0 when performing concurrent validity studies are unrealistic because any variation in measurement interval, missing data, environmental influence or physiological or mechanical difference will result in irreconcilable differences. However, until a true criterion measure for physical activity is found, mass-specific oxygen consumption rate will remain the best tool for validity studies.

1.3.3 Multiple sensors

Multiple sensor systems have been developed that entail attaching multiple sensors to the body trunk and extremities. Intelligent Device for Energy Expenditure and Activity (IDEEA) system captures body and limb motions through five biaxial accelerometer sensors attached to the chest, thighs and feet (Zhang et al. 2003; Zhang et al. 2004). The system uses artificial neural network to recognize 32 types of activities such as jumping, walking, and running, stair climbing and descending. In an adult study, IDEEA correctly identified posture and limb movement and gait 98% of the time. Energy cost of specific activities requires assignment from a published compendium of physical activities which are available for adults (Ainsworth et al. 1993a; Ainsworth et al. 2000), but limited in children (Ridley et al. 2008; Ridley and Olds 2008). Another physical activity measurement system was developed for adults and children that incorporated inclinometers and triaxial accelerometers to capture body position and motion (Lanningham-Foster et al. 2005). Body posture was correctly identified, and accelerometer output correlated well with varying walking velocities. Weaknesses of multiple sensor systems are: 1) available systems are wired, not wireless, and therefore cumbersome and intrusive; 2) data requires complex, sophisticated data processing; and 3) limited validation in large and varying population samples.

1.3.4 Summary of Physical Activity Measurement Methods

This review of the various methods of measuring physical activity and physical activity associated energy expenditure, highlights the fact that each measurement method varies in accuracy, feasibility (especially in large studies of free-living populations), cost, and reactivity (i.e., likelihood of influencing the activity they are designed to measure) (LaPorte et al. 1985). This review of physical activity measurement methods should also convey the fact that the physical activity constructs one wants to quantify will have a direct influence on the selection of the method or tool used to measure it. Also, all methods do not measure all the constructs, nor do they measure the individual constructs equally well (see Tables 1.1 and 1.2). Having said this, Table 1.2 does highlight the fact that accelerometers deliver as much capability as indirect calorimetry with the added benefit of being much less obtrusive. However, for some research applications where activity mode and/or context are important, accelerometry would need to be supplemented with another measurement method such as a questionnaire.

Table 1.1. Methods of assessment and the characteristics of physical activity that can be assessed

Method of Measurement	Units of Measurement	Type of Output	Output Measure
Questionnaire	Time segments (often 10, 15, 30 min segments)	1. Frequency of PA 2. Intensity of PA 3. Duration of PA 4. EE of PA	1. # of bouts > criterion level 2. Number or % of bouts 3. # minutes > criterion level 4. Estimates based on METS
Heart Rate	Beats per minute	1. Frequency of PA 2. Intensity of PA 3. Duration of PA 4. EE of PA	1. # of bouts > criterion level 2. Average HR per day or interval 3. # minutes > criterion level 4. Estimates from calibration equations
Motion Sensors	Movement counts	1. Frequency of PA 2. Intensity of PA 3. Duration of PA 4. EE of PA	1. # of bouts > criterion level 2. Average counts per day or interval 3. # minutes > criterion level 4. Estimates from calibration equations
Direct Observation	Activity rating	1. Frequency of PA 2. Intensity of PA 3. Duration of PA 4. EE of PA	1. # of bouts > criterion level 2. Number or % of bouts 3. # minutes > criterion level 4. Estimates based on METS
Pedometers	Step counts	1. Frequency of PA 2. Intensity of PA 3. Duration of PA 4. EE of PA	1. NA 2. NA 3. Number of steps taken 4. NA
Doubly Labeled Water	CO_2 production	1. Frequency of PA 2. Intensity of PA 3. Duration of PA 4. EE of PA	1. NA 2. NA 3. NA 4. Total energy expenditure
Indirect Calorimetry	O_2 consumption	1. Frequency of PA 2. Intensity of PA 3. Duration of PA 4. EE of PA	1. # of bouts > criterion level 2. Average VO_2 level 3. Monitored time above threshold 4. Total energy expenditure

Reproduced from Welk and colleagues (2000)

Table 1.2. Listing of physical activity measurement methods by constructs each instrument is capable of assessing

Method	Frequency	Intensity	Duration	Mode	Context	Energy Expenditure
Diary	Y	Y	Y	Y	Y	N
Questionnaire	Y	Y	Y	Y	Y	N
Accelerometer	Y*	Y*	Y*	N	N	Y*
Heart rate monitor	Y*	Y*	Y*	N	N	N
Pedometer	N	N	N	N	N	Y*
Observation	Y	Y	Y	Y	Y	N
Doubly labelled water	N	N	N	N	N	Y
Indirect calorimetry	Y*	Y*	Y*	N	N	Y
Caloric intake	N	N	N	N	N	Y

Y = yes, can assess that aspect of physical activity; N = no, cannot assess that aspect of physical activity; asterisk (*) denotes that this information is available for only some models of this type of instrument.
Notes: i) This is not an exhaustive list of the methods available to measure physical activity, nor is it a complete list of the constructs of physical activity; ii) Adapted from Mahar and Rowe (2002).

Effective population measurement of physical activity and/or sedentary behaviour allows for the: 1) baseline prevalence of physical activity and/or sedentary behaviour to be assessed, 2) tracking of physical activity and/or sedentary patterns throughout the lifespan, 3) identification of subgroups at high risk, 4) assessment of trends over time for the tracking of provincial/national targets, 5) evaluation of interventions, policies, and programs, 6) analysis of systemic changes in counselling and environmental design 7) determination of dose-response and measurement issues, 8) budgeting of public health resources, 9) development of population-specific physical activity interventions (Macera and Pratt 2000). With all these benefits, it is not surprising that there has been keen interest in monitoring physical activity and sedentary behaviours. Indeed, in recent years there has been a widespread call for improved research and surveillance of many chronic disease related health promotion measures, including physical activity (Daar et al. 2007).

1.3 Statement of the Problem

Physical activity is a complex and multidimensional human behaviour (LaPorte et al. 1985). Measuring the quantity and quality of physical activity requires the use of valid and reliable methods (Caspersen et al. 1998). Unfortunately, the exposure assessments in physical activity epidemiology are often crude which can contribute to inconsistent results among studies (Lagerros 2009; Lagerros and Lagiou 2007a). Moreover, doubt remains over the optimal and minimal volume (i.e., frequency, duration and intensity) of physical activity required to achieve health benefits (Warburton et al. 2007; Warburton et al. 2006).

Accurate measurements of physical activity are crucial to our understanding of the activity–health relationship, estimating population prevalence, identifying correlates, detecting trends, and evaluating the efficacy of interventions (Dollman et al. 2008a). These research endeavours have encouraged researchers to seek valid, reliable, and logistically feasible methods to measure physical activity. Fortunately, recent advances in low power, low cost, electronic sensors has lead to an increase in movement sensing technologies, such as pedometers and accelerometers (Chen and Bassett, Jr. 2005). These technologies have become progressively smaller and more sophisticated, allowing these measurement tools to move out of the laboratory and into the field (Janz 2006). In fact, accelerometry-based physical activity monitors are one of the most commonly used devices for assessing free-living physical activity (Welk 2002). However, accelerometers are not without problems, including frequent malfunctions, reduced participant compliance, and issues related to the standardization and optimization of accelerometry analytical techniques (Adamo et al. 2009; Esliger et al. 2005; Olds et al. 2007).

Therefore, the overall objective of this thesis was to determine the optimal accelerometer model to use to develop a comprehensive physical activity and sedentary behaviour profile and to apply the novel profiling methods in an order to gain new insights into children's physical activity. Three studies were necessary to realize this objective. The first study assessed the reliability of three market-leading accelerometer models; thereby informing longer term accelerometer purchasing decisions. The second study reviewed the literature on physical activity and sedentary behaviours in an effort to construct a comprehensive list of outcome variables, including their method of calculation, required to create a detailed physical activity profile. The third and final paper acted as a proof of concept to determine if the newly developed physical activity profile could actually quantify the differences in physical activity and sedentary behaviours in four groups of children known to differ in their lifestyle-embedded physical activity. The three studies together will help enhance the best practices in the accelerometric profiling of physical activity and sedentary behaviour in both children and adults.

1.3.1 Aims of Study 1

The purpose of this study was to determine which of the three most commonly used accelerometer models Actical (Mini Mitter Co., Inc., Bend, OR), Actigraph model 7164 (Actigraph, Fort Walton Beach, FL), or RT3 (Stayhealthy, Inc., Monrovia, CA) has the best intra- and inter-instrument reliability, using a mechanical laboratory setup. Secondly, this study aimed to determine the individual and combined effects of acceleration and frequency of movement on accelerometer count output.

1.3.1 Aims of Study 2

This review paper explores the physical activity and sedentary behaviour profile that can be acquired through objective monitoring, with a focus on accelerometry. Using previously collected objective data, a detailed physical activity profile is presented and case study examples of data utilization and interpretation are provided. The rich detail captured through comprehensive profiling creates new surveillance and study possibilities and could possibly inform new physical activity guidelines. Data are presented in various formats to demonstrate the dangers of misinterpretation when monitoring population adherence to Canada's physical activity guidelines. Recommendations for physical activity and sedentary profiling are provided and future research needs identified.

1.3.1 Aims and Hypotheses of Study 3

The purpose of this study was to profile the physical activity and sedentary behaviours of Old Order Amish (OOA), Old Order Mennonite (OOM), and contemporary-living children as a means of assessing the influence of lifestyle. Hypothesis 1 was that group differences in physical activity would be evident (i.e., Amish > Mennonite > contemporary-living children). Hypothesis 2 was that group differences in sedentary time would be evident (i.e., contemporary-living > Mennonite > Amish children). Hypothesis 3 was that the time of the day and the day of the week when most (majority) of the physical activity occurring in Amish and Mennonite children would be different from that occurring in the contemporary-living children.

Chapter 2: Study 1

Title: **Technical reliability assessment of three accelerometer models in a mechanical setup**

Study 1 has been published as an original investigation article in a peer-reviewed journal (Esliger et al. 2006). With the exception of the some minor wording and/or format changes that were necessary for the conversion to graduate thesis format, it is presented in its published form. The introduction section below may repeat key aspects of the review of literature directly pertinent to the purpose of the study.

2.1 Introduction

It is generally believed that the association between physical activity and health outcomes might be stronger if physical activity measurements were more accurate (U.S.Department of Health and Human Services 1996). More accurate assessments of free-living physical activity would help to: characterize the relationship between physical activity and disease prevention (i.e., the dose/response relationship), assess the efficacy of intervention strategies, and monitor the physical activity patterns of various populations (Wood 2000). With these goals in mind, researchers are actively searching for valid and reliable measures of physical activity (Caspersen 1989). This search has led to the increased availability of a wide variety of objective monitoring technologies. The research application of these technologies has resulted in the accrual of a significant body of literature on objective physical activity assessment, a large portion of which involves accelerometers (up to 90 articles per year in 2003 and 2004) (Troiano 2005). Indeed, accelerometry-based physical activity monitors are one of the most commonly used devices for assessing free-living physical activity (Welk 2002). Moreover, the use of accelerometers in large-scale surveillance studies is on the rise (e.g., National Health and Nutrition Examination Survey (NHANES) (National Center for Health Statistics 2005) and the Physical Activity Levels in Children and Youth study (PACY)) (Thompson et al. 2005).

Although the literature suggests that accelerometer technology and its applications have progressed significantly, information is lacking in key areas. As a result, in December 2004 a conference titled *Objective Monitoring of Physical Activity: Closing the Gaps in the Science of Accelerometry* was hosted by the School of Public Health, Department of Nutrition at the University of North Carolina. The proceedings from the three day meeting were assembled in article format and published as a supplement. The final paper authored by Ward et al. (2005) titled *Accelerometer Use in Physical Activity: Best Practices and Research Recommendations* summarized the salient points of the meeting. In it, the authors identified the need for studies that compare the validity and inter-instrument reliability of different models of accelerometers. Studies of this nature were seen as critical for accelerometer model selection but were deemed equally important as a means to scrutinize the quality and objectivity of the available reliability evidence (Trost et al. 2005).

The accelerometer reliability research published to date can be divided into two categories: studies conducted using a mechanical apparatus or those employing some form of subject mounted setup. The subject mounted setups can be further subdivided into laboratory-based activity assessment and the more practical, but less controlled situations of free-living activity assessment. Mechanical setups, by virtue of the precise control of the experimental conditions, are able to determine the variability attributed solely to the accelerometer. As with any method of measurement, it is important to identify and quantify the different sources of variation so actions can be taken to try and reduce or control them. This is important because if the measurement error intrinsic to the accelerometer is found to be small, then focus can shift to other sources of variation (e.g., position worn on the body, variation over time (e.g., day-to-day, week-to-week, season-to-season, etc.)) (Metcalf et al. 2002). Moreover, quantifying the inherent variation in accelerometer models allows for better interpretation of results and helps inform accelerometer purchasing decisions.

Researchers have used various mechanical apparatuses to oscillate accelerometers in various axes in an effort to assess reliability. Examples include turntables (Metcalf et al. 2002), rotating wheel setups (Brage et al. 2003) and vibration tables (Powell et al. 2003). These apparatuses allow the researcher to control the magnitude of the acceleration being imparted as well as the frequency of the oscillation, two key variables that contribute to the accelerometer's output. However, technical reliability studies to date have assessed only one accelerometer model and could only accommodate a small number of instruments at one time. Therefore, the purpose of this study was to determine which of the three most commonly used accelerometer models (Actical (Mini Mitter Co., Inc., Bend, OR); Actigraph model 7164 (Actigraph, Fort Walton Beach, FL); RT3 (Stayhealthy, Inc., Monrovia, CA); see Table 2.1 for specifications) has the best intra- and inter-instrument reliability using a mechanical laboratory setup. Secondly, this study aimed to determine the individual and combined effect of acceleration and frequency of movement on accelerometer count output. To the authors' knowledge, this study is the first to simultaneously assess the reliability of multiple accelerometers and multiple models in a mechanical setup.

Table 2.1. Accelerometer specifications by model

Model	Dimensions (LxWxH) (mm)	Weight (grams)	Piezosensor Orientation	Dynamic Range ($m \cdot s^{-2}$)	Frequency Range (Hz)
Actical	28 x 27 x 10	17	omnidirectional*	0.5-98.1	0.5-3.0
Actigraph†	51 x 38 x 15	43	uniaxial	0.5-19.6	0.25-2.5
RT3	71 x 56 x 28	65	triaxial**	0.5-19.6	2.0-10.0

†Note: The Actigraph 7164 has recently been replaced by a newer model (GT1M) with enhanced features.
*although affected by motion in all planes, the Actical is most sensitive to vertical movement
**sensitive to motion along three axes (vertical (X), mediolateral (Y), and anterioposterior (Z))

2.2 Materials and Methods

2.2.1 Hydraulic Shaker Table

All reliability testing was completed using a hydraulic shaker table (Figure 2.1). The shaker table was driven by a hydraulic cylinder (Sheffer, 1-1/18HHSL6ADY) controlled by an electrohydraulic servo valve with cylinder position feedback. A position transducer (Lucas 5000, DC-E) was used to measure position of the table and a high grade control accelerometer (calibrated at 98.1 $mV \cdot g^{-1}$ ±3.6%) (B&K model 4371) was attached to the table to measure vertical acceleration. The acceleration signal was transmitted to a charge amplifer (B&K model 2635) and band-passed filtered at 3 KHz. The amplifier input was provided by a function generator, which was programmed to accurately and reliably oscillate the platform at the various testing conditions using a sinusoidal oscillation procedure. The separation of the hydraulic power supply unit from the shaker table helped to minimize the mechanical vibration in the mechanical setup.

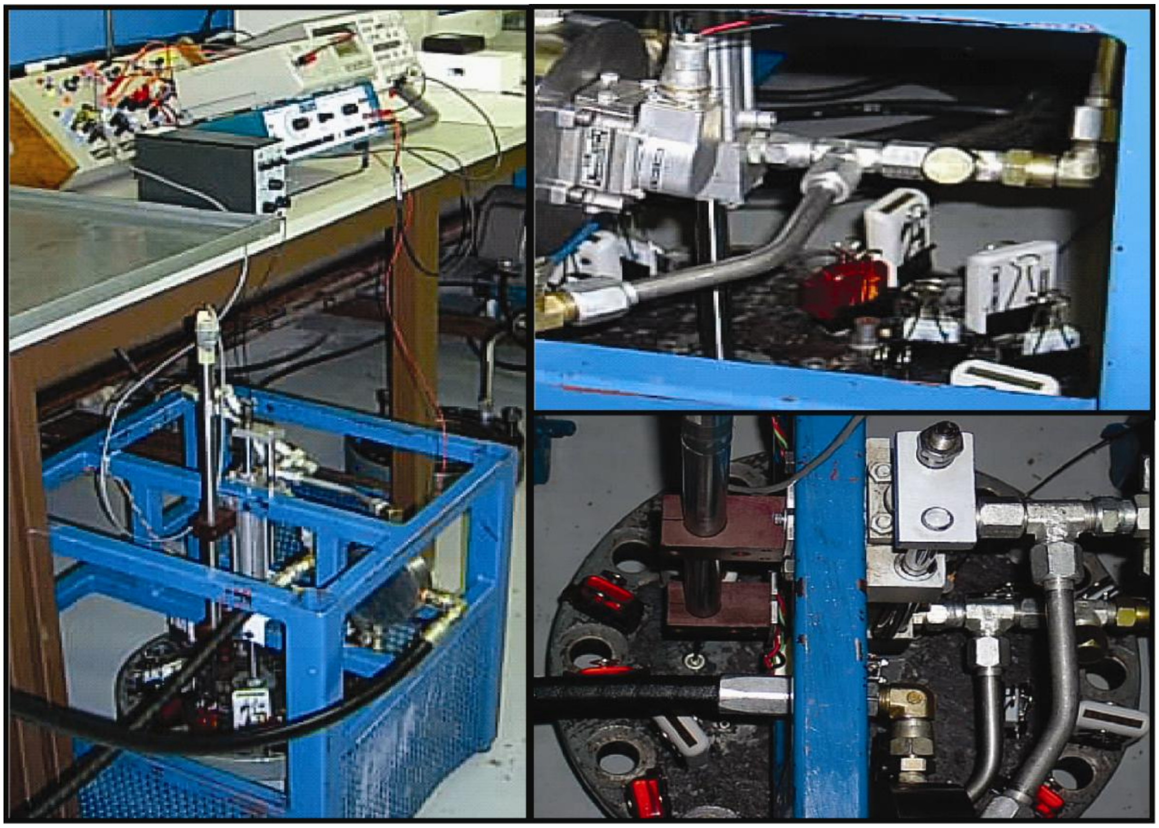


Figure 2.1. The hydraulic shaker table complete with input controls and external power supply (left) and shaker platform for adhering multiple accelerometers (right top and bottom).

The shaker table testing conditions were restricted by the displacement amplitude of the shaker plate (approximately 6.5 cm). Within this amplitude range the possible conditions of acceleration and frequency of oscillation are described by the equation:

$$\text{acceleration } (\text{m}\cdot\text{s}^{-2}) = (\text{amplitude (m)} \cdot \text{frequency}^2 \, (\text{rad}\cdot\text{s}^{-1}) \quad (2.1)$$

The six different conditions chosen were selected to produce a range of physiologically relevant accelerometer counts from light to moderate to hard within the limitations of the shaker plate (Table 2.2). When compared to treadmill calibration studies reported in the literature on the Actical (Puyau et al. 2004), these six conditions range in locomotive speed from approximately 2.5-4.75 mph. When compared to treadmill calibration studies using the Actigraph (Trost et al. 1998), the conditions range in locomotive speed from approximately 2.5-6.75 mph. Finally, when compared to treadmill calibration studies using the RT3 (Rowlands et al. 2004), the conditions range from approximately 1.0-3.25 mph. Further, these conditions were chosen to allow for independent assessments of both acceleration and frequency on accelerometer reliability. This was achieved by selecting three conditions at 0.5 g allowing only the frequency of oscillation to change and similarly, by selecting three conditions at 2.5 Hz allowing only acceleration of the shaker plate to change.

Table 2.2. Six different testing conditions varying in acceleration and/or frequency

Condition	Force (g)	Frequency (Hz)	Acceleration ($m \cdot s^{-2}$)	Amplitude (m)	Work·kg^{-1} ($m^2 \cdot s^{-2}$)
1	0.50	2.50	4.90	0.0198	0.0970
2	0.50	2.00	4.90	0.0311	0.1524
3	0.50	1.50	4.90	0.0552	0.2705
4	1.00	2.50	9.81	0.0398	0.3904
5	1.00	2.00	9.81	0.0621	0.6092
6	1.25	2.50	12.26	0.0497	0.6093

Note: Although the testing conditions were administered in random order to minimize the possibility of an order effect, they are organized above from the least intense to the most intense (condition 1-6) based on the product of acceleration and amplitude (i.e., Work·kg^{-1}).

2.2.2 Experiment One

Fifteen accelerometers, five of each of three models (Actical, Actigraph, and RT3), were initialized to collect data using one minute epochs. The computerized initialization function of the Actical and the Actigraph made time synchronization of these two models easy to attain. In the case of the five RT3s the external start buttons were simultaneously pressed at the exact time (using the initialization PC clock) the Actical and Actigraph were set to begin data collection. The triaxial RT3 was set to vector magnitude mode thereby combining count data from all three axes. The accelerometers were mounted to the surface of the shaker plate (surface area approximately 1500 cm^2) using industrial wax. Care was taken to ensure that the monitors were secured firmly and were positioned vertically along their sensitive axis in order to maximize and standardize the output of the piezosensor. In the case of the triaxial RT3, it was positioned so the vertical oscillation was along the x-axis.

The hydraulic shaker table was switched on once all 15 accelerometers were in place and the first of the random ordered conditions was set, thereby accelerating all 15 monitors simultaneously in the vertical plane. The shaker table was warmed up to achieve optimal functioning of the hydraulics and the control electronics thereby ensuring the proper execution and maintenance of each of the six conditions for the seven minute test periods. All conditions began at the turn of a new minute on the PC clock which was recorded along with the condition end time for data analysis purposes. After approximately 60 minutes of data collection (12 minute warm-up + (6 conditions x 7 minutes per condition) + (6 x 1 minute transitions between conditions)) the accelerometers were removed from the shaker plate and downloaded to the initialization PC for further analysis. Data were imported into a customized spreadsheet application using the common epoch-by-epoch time stamp to align the data vertically across models. The recorded condition start and end times were identified and the middle five minutes of each condition were identified and exported from the spreadsheet application into a statistical package for further analysis (SPSS 13.0).

2.2.3 Experiment Two and Three

Based on promising reliability data from Experiment One, the Actical and Actigraph accelerometer models were selected to undergo more robust reliability assessments. In Experiment Two, using exactly the same data collection and analysis procedures as described above, 39 Actical accelerometers from a different lot of 40 devices (one was found to be faulty upon delivery) were simultaneously accelerated in the vertical plane using the same six conditions already described (Table 2.2). In Experiment Three, again using a similar data collection and analysis procedure as in the first experiment, 50 Actigraph accelerometers from a different lot were simultaneously accelerated in the vertical plane. However, because two devices malfunctioned, all analyses were performed on a sample of 48 Actigraphs.

2.2.4 Statistical Analyses

2.2.4.1 Intra-instrument reliability

To determine the variability within a given accelerometer, standard deviation (SD), standard error of the measurement (SEM), and coefficient of variation (CV_{intra}) were calculated from the replicate minutes (i.e., minutes 1-5) within each condition. This minute by minute variability characterizes the accelerometers' ability to consistently measure the given condition rendered by the shaker table. This is a noteworthy distinction as most intra-instrument reliability analyses focus on within accelerometer, between trial variability. As a result, less variability (i.e., technological error) is expected using the present calculation methods as no trial effect is present.

2.2.4.2 Inter-instrument reliability

To determine the variability between like-model accelerometers (i.e., between units) standard deviation, standard error of the measurement, coefficient of variation (CV_{inter}) were calculated for each of the six testing conditions. In addition, intra-class correlation coefficients (ICC) with a two-way random effects model for absolute agreement were calculated. To determine the independent effect of acceleration and frequency on count output across models, repeated measures ANOVA were used. Where significance was found, post hoc analyses were conducted via paired *t* tests. In all cases alpha was set at $P < 0.05$.

2.3 Results

2.3.1 Experiment One

The summary accelerometer count data across all six conditions and models (Table 3) suggests that the Actical accelerometer had better intra-instrument reliability (mean CV_{intra} = 0.4%) followed by the Actigraph (4.1%) and the RT3 (46.4%), respectively. However, the Actigraph accelerometer had better inter-instrument reliability (mean CV_{inter} = 4.9%) followed by the Actical (15.5%) and the RT3 (42.9%), respectively (Table 2.3). The same hierarchy in inter-instrument reliability was found with the calculation of the average measure intra-class correlation coefficients (R = 0.995, 0.985, 0.910 for the Actigraph, Actical, and RT3, respectively).

Table 2.3. Comparison of mean counts per minute and reliability statistics across the six testing conditions for the three accelerometer models (n=5 per model)

Conditions				Intra-Instrument Reliability			Inter-Instrument Reliability		
Acceleration ($m \cdot s^{-2}$)	Frequency (Hz)	Model	Counts	SD	SEM	CV	SD	SEM	CV
		Actical	2688	7	3	0.3	537	240	20.0
4.9	2.5	Actigraph	1877	134	60	7.1	126	63	6.7
		RT3	1088	469	210	43.2	442	198	42.4
		Actical	2465	27	12	1.1	493	220	20.0
4.9	2	Actigraph	2668	59	26	2.2	102	51	3.8
		RT3	339	334	149	106.9	318	142	94.8
		Actical	1960	4	2	0.2	312	140	15.9
4.9	1.5	Actigraph	3081	5	2	0.2	135	67	4.4
		RT3	584	78	35	13.2	76	34	12.7
9.81	2.5	Actical	6832	24	11	0.3	1005	450	14.7

		Actigraph	5682	63	28	1.1	223	111	3.9
		RT3	2242	895	400	40.0	765	342	35.3
		Actical	5003	19	8	0.4	690	308	13.8
9.81	2	Actigraph	5755	252	113	4.4	178	89	3.1
		RT3	2009	773	346	38.9	700	313	35.5
		Actical	8275	25	11	0.3	706	316	8.5
12.26	2.5	Actigraph	7230	688	308	9.5	546	273	7.7
		RT3	3005	1001	448	36.2	1072	479	36.9
		Actical	**4537**	**18**	**8**	**0.4**	**624**	**279**	**15.5**
Overall Mean		**Actigraph**	**4382**	**200**	**90**	**4.1**	**218**	**109**	**4.9**
		RT3	**1545**	**592**	**265**	**46.4**	**562**	**251**	**42.9**

Holding the frequency of oscillation of the shaker plate constant at 2.5 Hz allowed for an independent assessment of the impact of varying acceleration conditions on the magnitude of the count output. As expected, increasing the magnitude of acceleration increased the count output in all accelerometer models (Figure 2.2). However, holding acceleration constant at 4.9 $m \cdot s^{-2}$ and increasing movement frequency produced seemingly counter-intuitive results; that is, no consistent relationship was found between models with increasing frequency of oscillation of the shaker plate (Figure 2.3). In fact, the Actical count output increased with increasing frequency, while the Actigraph counts decreased and the RT3 counts both decreased and increased.

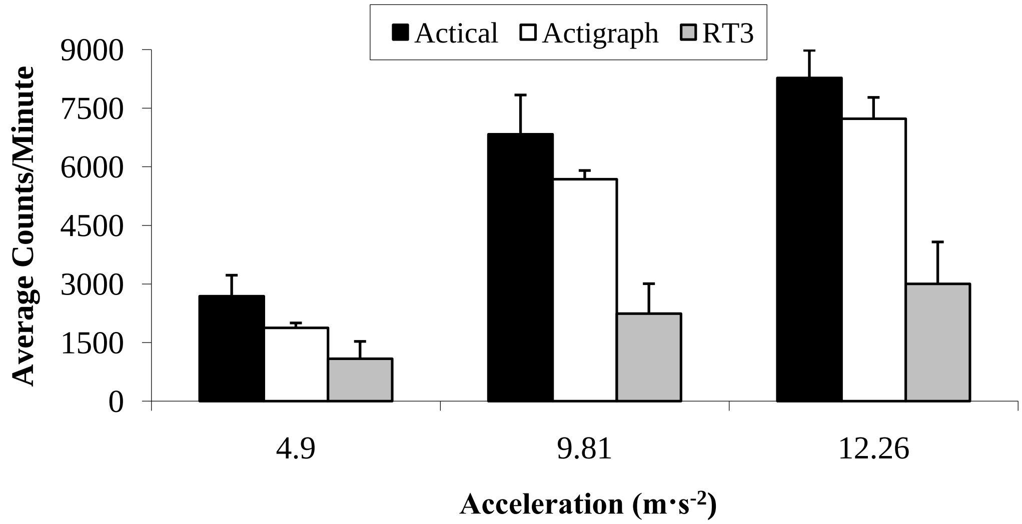


Figure 2.2. Between model comparison of the effect of acceleration on count magnitude and variability (frequency held constant at 2.5 Hz) (n=5 per model).

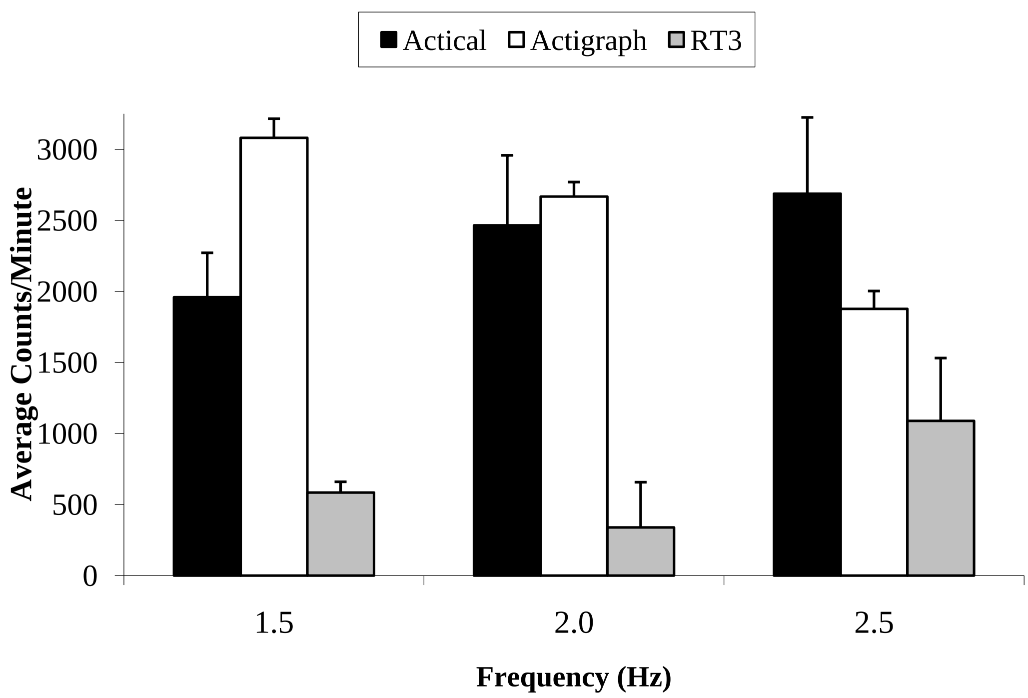


Figure 2.3. Between model comparison of frequency effects on count magnitude and variability (acceleration held constant at 4.9 $m \cdot s^{-2}$) (n=5 per model).

2.3.2 Experiment Two and Three

Further testing of a larger sample of Actical accelerometers (n=39) showed that the intra-instrument reliability remained relatively stable in Experiment Two (CV_{intra} = 0.5%) compared to Experiment One (0.4%) (Table 2.4). However, the inter-instrument reliability improved markedly from an average CV_{inter} of 15.5% in Experiment One, to 5.4% in Experiment Two (Table 2.4). Further testing of Actigraph accelerometers in Experiment Three (n=48) also produced differing results compared to Experiment One. The second set of analyses on the Actigraphs produced better intra-instrument reliability (3.2% compared to 4.1% in Experiment One) (Table 2.5). However, the inter-instrument reliability of the Actigraph decreased from a CV_{inter} of 4.9% in Experiment One, to 8.6% in Experiment Three (Table 2.5).

Table 2.4. Comparison of mean counts per minute and reliability statistics across the six testing conditions for 39 Actical accelerometers

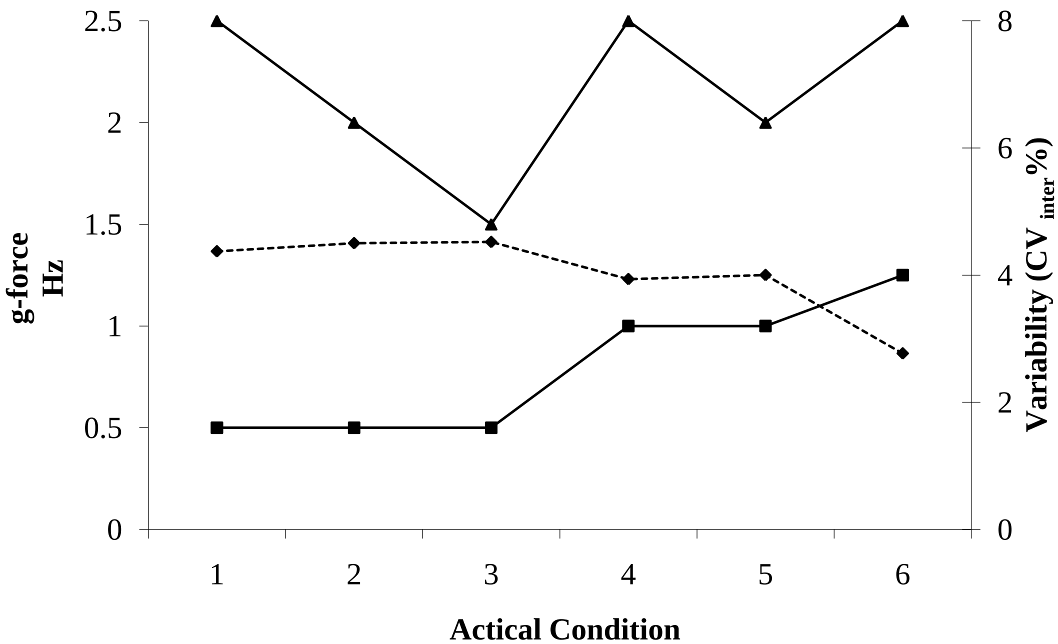
Conditions			Intra-Instrument Reliability			Inter-Instrument Reliability		
Acceleration ($m \cdot s^{-2}$)	**Frequency (Hz)**	**Counts**	**SD**	**SEM**	**CV**	**SD**	**SEM**	**CV**
4.9	2.5	2499	8	4	0.3	109	18	4.4
4.9	2.0	2651	6	2	0.2	119	19	4.5
4.9	1.5	2409	7	3	0.3	109	17	4.5
9.81	2.5	5841	65	29	1.1	230	37	3.9
9.81	2.0	6550	7	3	0.1	262	42	4.0
12.26	2.5	6988	67	30	1.0	193	31	2.8
Overall Mean		**4490**	**26**	**12**	**0.50**	**171**	**27**	**4.02**

Table 2.5. Comparison of mean counts per minute and reliability statistics across the six testing conditions for 48 Actigraph accelerometers

Conditions			Intra-Instrument Reliability			Inter-Instrument Reliability		
Acceleration ($m \cdot s^{-2}$)	**Frequency (Hz)**	**Counts**	**SD**	**SEM**	**CV**	**SD**	**SEM**	**CV**
4.9	2.5	2008	105	47	5.2	217	31	10.8
4.9	2.0	3310	6	3	0.2	255	37	7.7
4.9	1.5	4667	26	12	0.6	342	49	7.3

9.81	2.5	6016	379	169	6.3	581	84	9.6
9.81	2.0	9309	15	7	0.2	608	88	6.5
12.26	2.5	7907	528	236	6.6	763	110	9.6
Overall Mean		**5536**	**176**	**79**	**3.17**	**461**	**67**	**8.61**

Presenting the relative variability data of the two accelerometer models in graphical rather than tabular form highlights the intensity effect. The variability of the Actical accelerometer is negatively related to the intensity of the shaker plate testing condition (Top of Figure 2.4). As the acceleration of the condition increases the inter-instrument variability decreases; thus, it is the acceleration, rather than the frequency, that affects the variability of the Actical output. However, a comparable graph (Bottom of Figure 2.4) depicting the Actigraph data shows no relationship between acceleration and relative inter-instrument variability; rather, it suggests that frequency is more closely related (again negatively) to accelerometer variability. This apparent heteroscedasticity went undetected by the ICC values which increased for the Actical from 0.985 in Experiment One to a perfect value of 1.00 in Experiment Two. Likewise, the already high ICC values of the Actigraph increased from 0.995 to 0.999 from Experiment One to Experiment Three.



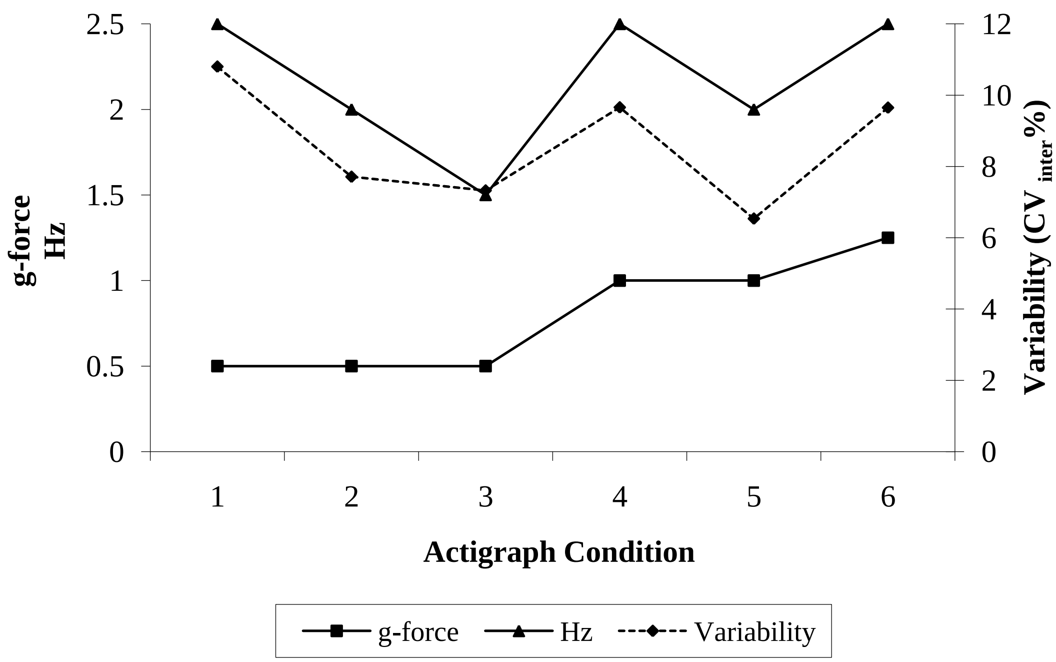


Figure 2.4. Relationship between acceleration and frequency of oscillation and accelerometer variability. Top: Actical (n=39). Bottom: Actigraph (n=48).

In Experiment Two and Three, when the frequency was held constant at 2.5 Hz and the acceleration increased from 4.9 to 9.81 to 12.26 $m \cdot s^{-2}$, both the Actical and Actigraph count output responded by increasing in magnitude, the same as in Experiment One. Meanwhile, when the acceleration of the shaker table was held constant at 4.9 m·s^{-2}, the Actical count output did not follow the same pattern of increasing magnitude, as the frequency of oscillation increased from 1.5 to 2.0 to 2.5 Hz (Figure 2.5). However, the Actigraph count output showed its characteristic decrease in count output as the frequency increased (Figure 2.5).

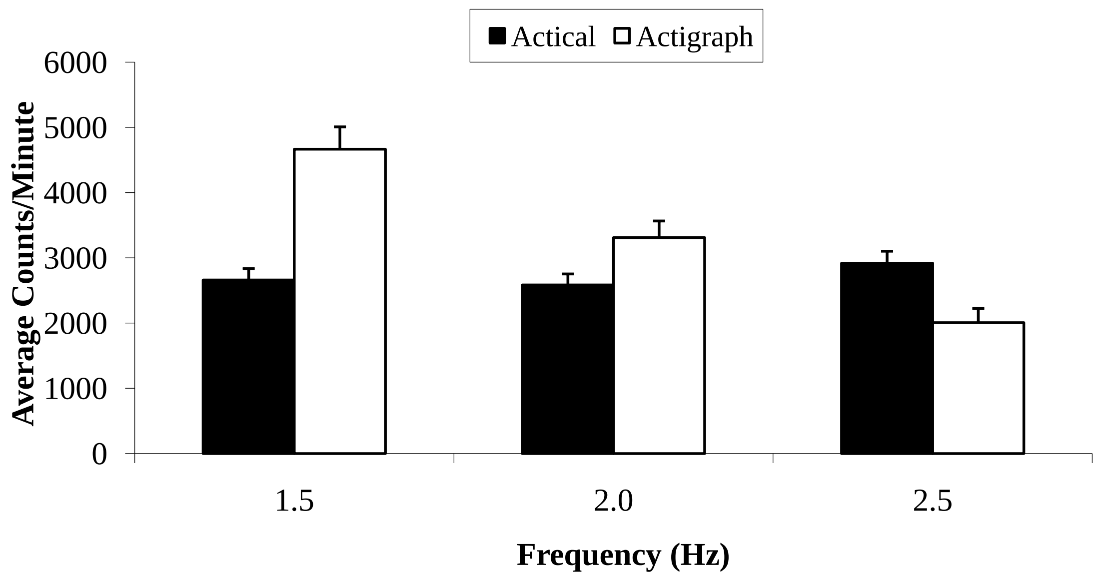


Figure 2.5. Between model comparison of frequency effects on count magnitude ($\overline{X}$ ±SD) and variability (acceleration held constant at 4.9 m·s^{-2}) (Actical n=39; Actigraph n=48).
Note: All three frequency combinations were significantly different within each accelerometer model ($P < 0.05$).

Actigraph count output increased as frequency decreased at a given acceleration resulting in a graded count output across the intensity spectrum (Figure 2.6). However, because the Actical accelerometers showed very little count variation across the three testing frequencies at 4.9 m·s^{-2} (i.e., conditions 1-3), a gap appears in the middle of the count output intensity spectrum (Figure 2.6). In addition to the differences in the distribution of count outputs across the intensity spectrum, the order of the conditions also differs between accelerometer models.

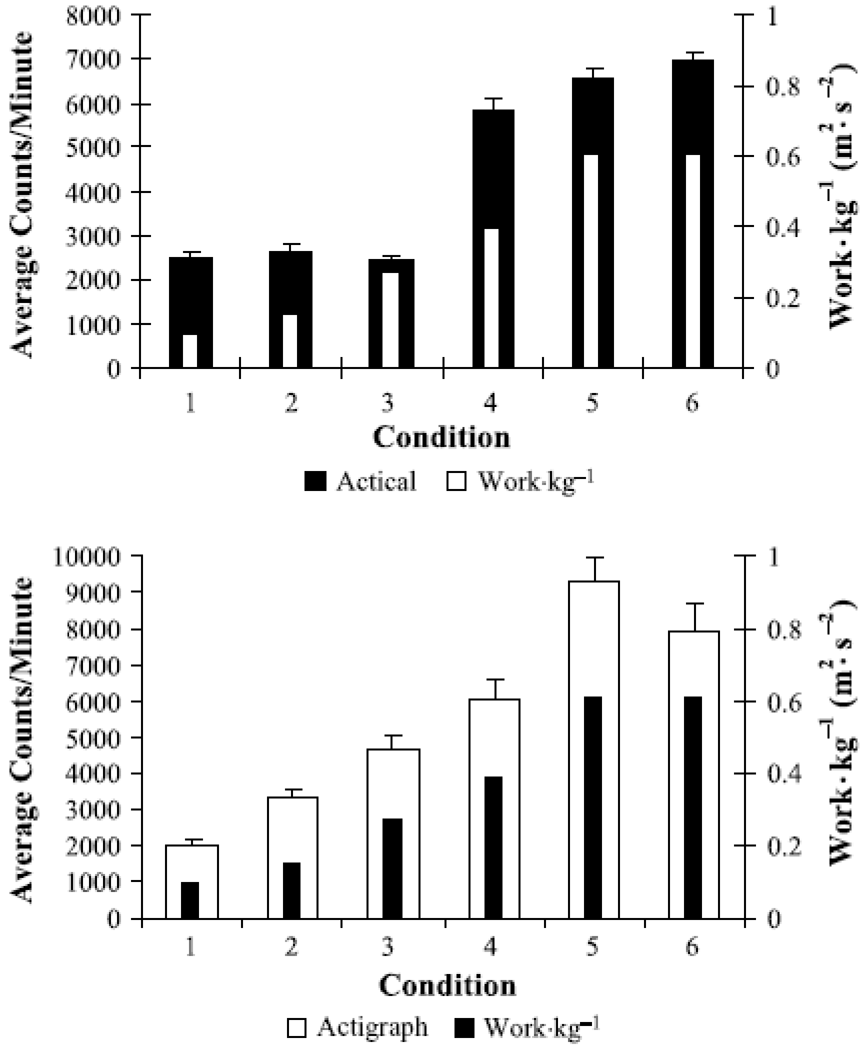


Figure 2.6. Between model comparison of the combined effects of acceleration and frequency (i.e., Work·kg^{-1}) on count magnitude ($\overline{X}$ ±SD) across six testing conditions (Actical n=39 (top); Actigraph n=48 (bottom)).

2.4 Discussion

2.4.1 Experiment One

In Experiment One the Actical was found to have the best intra-instrument reliability while the Actigraph had the best inter-instrument reliability, with the RT3 generally performing poorly. The exceptionally poor reliability of the RT3 accelerometers may be explained by the fact that the RT3 has a much wider frequency range than both the Actical and Actigraph (upper cut-off frequency of 10 Hz compared to 3.0 and 2.5 Hz, respectively). It has been suggested that an overly wide bandwidth filter could allow physiologically unrelated vibrations (i.e., noise) to be included in the signal (Chen and Bassett, Jr. 2005). Although the separation of the hydraulic power supply unit and the shaker table in our experimental setup helped minimize vibration in the mechanical setup, it could not ensure it. Further complicating the issue of reliability is the fact that the lower cutoff frequency of the RT3 is 2.0 Hz, which is greater than one, and equal to two, of the six testing conditions used in the present study. Finally, the fact that the RT3 accelerometer is triaxial may have increased its ability to detect vibrations in the mediolateral and anterior-posterior axes, something neither of the other monitors were capable of doing. These explanations suggest that a large portion of the variability in the RT3 may be due to hardware and setup issues. Nevertheless, the following attributes of the RT3 can be considered limitations: its large size, its external display, the presence of an external button, the accessible battery compartment, and the fact that it is not waterproof.

The excellent intra- and much weaker inter-instrument reliability of the Actical in Experiment One were surprising and disconcerting. This level of inter-instrument variability raises quality assurance concerns. Most accelerometer companies perform some form of calibration procedure as part of a quality assurance check before filling an order (Welk 2005). Experiment Two was conducted to assess the extent of the quality assurance concerns across a larger number of Actical accelerometers.

Although the Actigraph performed well, with both the intra- and inter-instrument variability falling below five percent, the existence of a discrepant trend in count output across frequencies between the Actical and the Actigraph suggested a validity concern (discussed in next section). Experiments Two and Three were performed to further assess this concern.

2.4.2 Experiment Two and Three

The results of Experiments Two and Three clearly indicate that under the mechanical testing conditions of these experiments, the Actical (CV_{intra} = 0.5%; CV_{inter} = 5.4%) is more reliable than the Actigraph (CV_{intra} = 3.2%; CV_{inter} = 8.6%). This suggests better inter-instrument calibration of the Actical by the manufacturer when compared to the lot of devices from Experiment One. To the authors' knowledge, this is the first technical reliability data published on the Actical. However, there are three such technical reliability studies available for comparison on the Actigraph accelerometer (Brage et al. 2003).

In the study by Brage and colleagues (2003), six Actigraph accelerometers were exposed to a host of acceleration and frequency conditions via a dual rotating wheel setup. The mean intra-instrument variability of the six Actigraphs was slightly higher (within instrument, between trial CV_{intra} = 4.4%) but comparable to that of the 48 Actigraphs in the present study. Likewise, over similar acceleration and frequency conditions the range of inter-instrument reliabilities reported (CV_{inter} ~ 5-12%) matched quite well with those in the present study. When presented with large inter-instrument variability, Brage et al. (2003) suggest that either a multipoint, unit specific calibration be used before and after each measurement period, or some form of post measurement adjustment be employed (i.e., covariate) during statistical analyses.

In a preliminary study by Fairweather and colleagues (1999), four Actigraphs were oscillated at 2.0 Hz using a mechanical shaker system. The only reliability data reported was for inter-instrument reliability (CV_{inter} ~ 3.0%) which was much better than that found in the present study. The difference in these results can be explained first, by the small number of accelerometers tested (i.e., homogeneous sample) and second, by the fact that only one testing condition was used. In a study by Metcalf et al. (2002), Actigraphs were rotated at medium and fast speeds via a turntable setup. Intra-instrument reliability (within instrument, between trials; n=7) ranged from 0.8-1.4% while inter-instrument reliability (n=23) was found to be 3.3% at both fast and medium speeds. At first glance the intra-instrument reliabilities look much better than those in the present study. However, if only similar frequency conditions from the present study are compared (i.e., fast speed of 120 $rev \cdot m^{-1}$ = 2.0 Hz and medium speed of 72 $rev \cdot m^{-1}$ = 1.2 Hz), then the reliability results align much better with the present study (aligned CV_{intra} = 0.17% and 0.56%, respectively). However, the inter-instrument reliability did not align as well (aligned CV_{inter} = 7.1% and 7.3% respectively), likely due to the larger, more heterogeneous sample of accelerometers in the present study.

To date, only one study has compared the inter-instrument reliability of different accelerometer models (1996). This study assessed four accelerometer models using a more applied approach employing standardized bouts of treadmill and outdoor running activity. The results of the generalizibility study concluded that overall, the Actigraph (n=10) was the most reliable accelerometer (CV_{inter} = 8.9%) compared to the Tritrac (the predecessor version of the RT3; n=9) (CV_{inter} = 9.4%), Biotrainer (IM Systems, Baltimore, MD; n=9) (CV_{inter} = 10%), and Actical (n=7) (CV_{inter} = 20.0%), respectively. Although not a technical reliability study, the inter-instrument reliability of the Actigraph was nearly equal to that of the present study. However, the high degree of variability in the Actical was much greater than in the present study, especially in Experiment Two. It is possible that the Actical monitors were acquired prior to the manufacturer being aware of potential issues in their calibration quality assurance.

The discrepant trend in count output across frequencies between the Actical and the Actigraph (Figure 2.3) was confirmed in Experiments Two and Three (Figure 2.5). This result is indeed intriguing as it suggests there is a validity issue at play. How can two accelerometer models designed to measure the same thing, produce very different trends when presented with the same testing conditions? Which one, if any, is correct? It is important to understand that accelerometers are accelerometer-based physical activity monitors, not instruments that merely record acceleration. As such, these instruments must consider both the frequency and acceleration of movement in order to validly assess physical activity.

The six testing conditions imposed on the Actical resulted in a bimodal distribution of the six mean count outputs (Figure 2.6). The gap in Actical output occurs because conditions 1-3 remain virtually unchanged despite changes in frequency and hence work performed. These results seem to call into question the validity of the Actical. Conversely, these same six conditions imposed on the Actigraph resulted in a distributed count output across the intensity spectrum (Figure 2.6). With the exception of a reversed order in conditions 5 & 6, the graded output of the Actigraph matches the theorized intensity spectrum based on the quotient of work and body mass (Table 2.2). The fact that there is general agreement between the Actigraph count output and mass specific work may provide evidence of instrument validity. However, data from the present study do not allow definitive conclusions regarding the validity of either accelerometer model.

The Actigraph user's manual presents the accelerometer frequency rage as 0.25-2.5 Hz which may be misleading as it seems to imply that movements inside this range are measured full scale while those outside this range are not registered at all. However, in the original Actigraph design study, Tryon and Williams (1996) describe the filter as a weighting function with optimal weight at 0.75 Hz that decreases as frequency increases or decreases. However, unlike Tryon and Williams, Brage et al. (2003) explicitly state that Actigraph output is only proportional to acceleration if frequency is held constant, thus suggesting that some form of frequency-dependent filter is present. The authors went on to develop a frequency-based correction factor that can be applied to raw Actigraph counts to restore linearity. Applying this correction factor to the Actigraph data in Experiment Three results in increased mean count output across all six conditions (due to the re-weighting) (Figure 2.7). Likewise, conditions 5 and 6 become properly ordered (i.e., aligning to Work·kg^{-1}) as a result of the frequency correction equation. The corrected data are consistent with the notion that at least a portion of the decline in Actigraph output with increasing frequency may be a result of bandwidth filtering procedures.

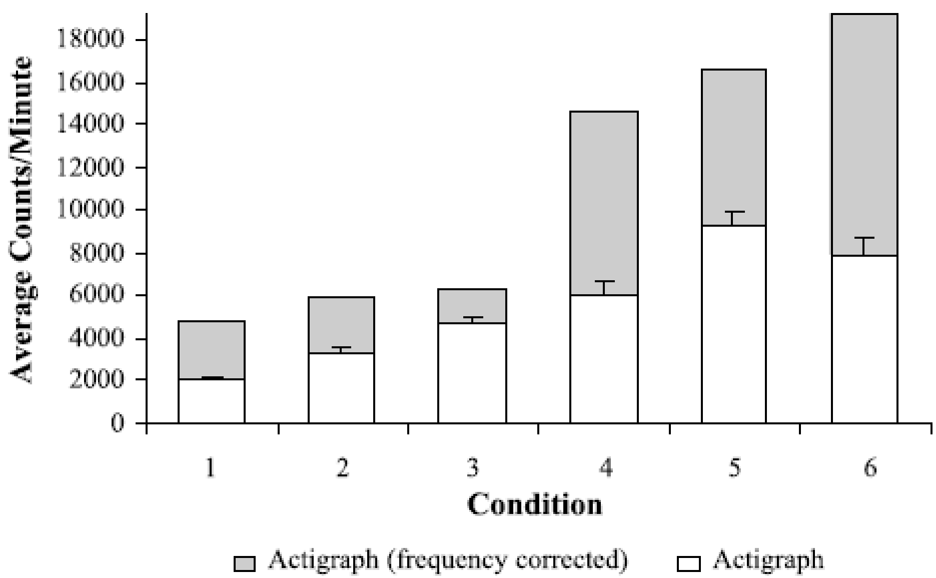


Figure 2.7. Comparison of frequency corrected Actigraph count data ($\overline{X}$ ±SD) across the six testing conditions (Actigraph n=48).

Unfortunately, no design specifications research comparable to that of the Actigraph (Tryon and Williams 1996) has been published on the Actical; therefore, the filtering specifics of this accelerometer model are unknown and in need of future research. Likewise, because the Actigraph 7164 has been phased out, replaced by the GT1M model, further studies are required to examine the comparability and technical reliability of this new Actigraph model.

That reliability sets the limit on validity is a fundamental tenet of science and as such, justifies the need for quality reliability research. Researchers employing accelerometers to assess physical activity would do well to start treating their accelerometers with the same care as those using metabolic carts. This means the initiation of proper calibration checks with each and every use. Obviously substitute the calibration gas with some form of mechanical apparatus that reliably oscillates the accelerometer across a host of intensity conditions. And of course, an a priori variability limit must be set (e.g., mean difference ≤ 5%). If such a calibration check was implemented with the data from Experiment Two and Three, seven (18%) of the Actical and 16 (33%) of the Actigraph accelerometers would be rejected as too variable for use (Figure 2.8). That the accelerometer units along the x-axes are ordered according to serial number is also of interest; in this manner, visual checks for batch/lot effects can easily be made. For example, looking at the data from the Actical, one can easily determine that units 19-23 are clustering (i.e., come from the same homogeneous batch). Further, one can readily see that units 1-18 are subject to more variability than units 24-39. These data clearly illustrate that batch effects can greatly influence reliability and therefore deserve consideration in reliability study designs.

The popularity of accelerometry as an objective measure of physical activity stems from its ability to provide direct, objective and detailed physical activity information (Esliger et al. 2005). However, the quality of information from accelerometers is only as good as the devices themselves. Therefore, it is important that both researchers and manufacturers work together to ensure both the reliability, and ultimately the validity, of these measurement devices. Finally, journal editors and peer-reviewers will have to do their part by demanding that proper reliability procedures be both followed and reported for successful publication.

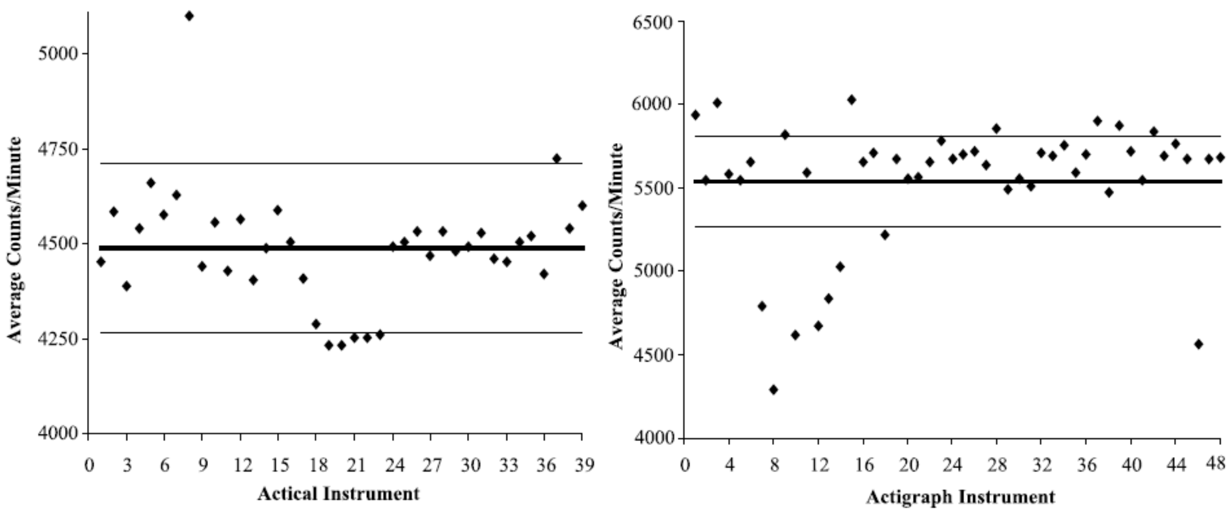


Figure 2.8. Calibration assessment of 39 Actical (left) and 48 Actigraph (right) accelerometers setting 5% variability limits.
Note: Middle line represents mean of the six testing conditions with the line above and below acting as the ±5% boundary.

2.5 Acknowledgements

The authors acknowledge Doug Bitner for his assistance with the mechanical setup and Dr. Kong Chen for his kind review of the manuscript. This study was funded by the Canadian Population Health Initiative of the Canadian Institute for Health Information.

Chapter 3: Study 2

Title: **Physical Activity and Sedentary Profiling: The Next Generation**

Study 2 has been published as a review article in a peer-reviewed journal (Esliger and Tremblay 2007). With the exception of the some minor wording and/or format changes that were necessary for the conversion to graduate thesis format, it is presented in its published form. The introduction section below may repeat key aspects of the review of literature directly pertinent to the purpose of the review.

3.1 Introduction

On September 24-25, 1984, the Centers for Disease Control (CDC) held a workshop on Epidemiologic and Public Health Aspects of Physical Activity and Exercise. The organizers (the new Behavioral Epidemiology and Evaluation Branch) believed that although the health benefits of physical activity were becoming established, several important knowledge gaps remained. In a process not unlike the recent initiative by the Canadian Society for Exercise Physiology (Tremblay et al. 2007c), ten scientific papers were commissioned to provide a summary of existing knowledge and to identify areas for future research (see Powell and Paffenbarger (1985) for a summary of the workshop). The article by LaPorte and colleagues (1985) entitled "Assessment of physical activity in epidemiologic research: problems and prospects" reviewed more than 30 different methods of measuring physical activity. The authors concluded that, although the resulting data were limited, surveys were the most practical approach for large-scale studies. Objective techniques (e.g., heart rate monitoring, movement sensors) were seen as promising, but experimental and cost prohibitive. The authors concluded that despite the difficulty in obtaining accurate measurements, a relatively strong association had been established between physical activity and health, and they suggested that improved methods of measurement should demonstrate even stronger associations.

Much has been learned over the subsequent two decades. Table 3.1 outlines a chronology of events that have been instrumental in shaping the field of physical activity measurement. Perhaps the most notable change has been the rapid growth in use of objective monitoring (e.g., accelerometers, global positioning systems (GPS), heart rate monitors, pedometers, etc.); this has provided much more robust and detailed physical activity information (Esliger et al. 2005; Schutz et al. 2001). Physical activity monitors have become progressively smaller, less expensive, and more sophisticated, allowing these measurement tools to move out of the laboratory and into the field. There has thus been a narrowing of the methodological gap between accuracy and feasibility for assessing physical activity (Figure 3.1). To date, the use of objective monitoring has been confined largely to experimental studies; however, at least two countries (Canada (Tremblay et al. 2007a) and the United States (Troiano 2005)), have now initiated national, objective physical activity surveillance (in both cases, using accelerometry). Nevertheless, the most common methods of measuring population-level physical activity are still questionnaire-based and are limited in their ability to provide accurate or detailed information (Sallis and Saelens 2000; Shephard 2003; Wareham and Rennie 1998).

Table 3.1. Selected milestones that contributed to the advancement of the study of physical activity measurement.

Date	Event Description	Focus/Title	Output/Outcome	Citation(s)
1984	CDC workshop on epidemiologic and public health aspects of physical activity and exercise	Workshop on epidemiologic and public health aspects of physical activity and exercise: a summary	Public Health Reports supplement published dedicated to the topic (with a key paper titled "Assessment of physical activity in epidemiologic research: problems and prospects")	(Powell and Paffenbarger, Jr. 1985) (LaPorte et al. 1985)
1984	NHLBI workshop on activity assessment methods for use in epidemiologic studies	Assessment methods for physical activity and physical fitness in population studies: report of a NHLBI workshop	Special report published summarizing the workshop	(Wilson et al. 1986)
1989	Key paper published	Physical activity epidemiology: concepts, methods, and applications to exercise science	Comprehensive review paper detailing the rise of physical activity epidemiology as an "area of study".	(Caspersen 1989)
1996	Key paper published	Determinants of physical activity in obese children assessed by accelerometer and self-report	This paper suggests that the predictors of physical activity level are different based upon the method of measuring physical activity.	(Epstein et al. 1996)
1996	Textbook published	Measuring physical activity and energy expenditure	1st comprehensive text dedicated to physical activity measurement	(Montoye et al. 1996)
1996	Release of the US Surgeon General's Report	Physical activity and health	Generated wide-scale recognition of the important link between physical activity and health	(U.S.Department of Health and Human Services 1996)
1999	International conference held at the Cooper Institute in Dallas, TX	Measurement of physical activity	RQES supplement published dedicated to the topic	(Wood 2000)
2000	Journal supplement commissioned by the International Life Sciences Institute	Measuring physical activity and energy expenditure	MSSE supplement published dedicated to the topic	(Montoye 2000)
2000	Dose-response symposium and consensus process held in Hockley Valley, ON (international in scope)	Physical activity and health	MSSE supplement published dedicated to the topic	(Kesaniemi et al. 2001)
2002	2002 U.S. National Institutes of Health (NIH) Funding Call Launched	Improving diet and physical activity assessment (R01)	Special Emphasis Panel created to award grants that support new diet and exercise assessment methods	(National Institutes of Health 2002)
2002	Textbook published	Physical activity assessments for health-related research	2nd comprehensive text dedicated to physical activity measurement	(Welk 2002)
2003-	U.S. implement largest objective	NHANES initiates objective	Public access data file containing accelerometry	(Troiano 2005)

2004	physical activity monitoring to date	monitoring of physical activity via accelerometry	data on a nationally representative sample of ~7000 survey participants	
2004	Scientific meeting held in Chapel Hill, NC	Objective measurement of physical activity: Closing the gaps in the science of accelerometry	MSSE supplement published dedicated to the topic	(Ward et al. 2005)
2006	Key paper published	Physical activity and clustered cardiovascular risk in children: a cross-sectional study (The European Youth Heart Study)	Cross sectional study aiming to characterize the association between physical activity and clustered CVD risk factors better with the use of objectively measured physical activity	(Andersen et al. 2006)
2006	Key paper published	Physical activity epidemiology: moving from questionnaire to objective measurement	Commentary article suggesting the physical activity can best be measured by a combination of activity monitors, questionnaires, and analytical techniques	(Janz 2006)
2006	Institute of Medicine (IOM) workshop held in Washington, DC	Adequacy of evidence for physical activity guidelines development	IOM report highlighting the need for better measurement of physical activity (naming objective monitoring as showing promise in this regard)	(West Suitor and Kraak 2007)
2007	Key paper published	Objectively measured physical activity and fat mass in a large cohort of children	Cross sectional study aiming to characterize the association between physical activity and obesity better with the use of objectively measured physical activity	(Ness et al. 2007)
2007-2009	Canada implements objective physical activity monitoring	CHMS initiates objective monitoring of physical activity via accelerometry	Began collection of 7-days of objectively measured physical activity data on a nationally representative sample of 5000 survey participants over a 2 year period	(Tremblay et al. 2007a)

Abbreviations: CDC- Centers for Disease Control; CHMS- Canadian Health Measures Survey; CVD-cardiovascular disease; MSSE-Medicine and Science in Sports and Exercise; NHANES- National Health and Nutrition Examination Survey; NHLBI- National Heart, Lung, and Blood Institute; RQES- Research Quarterly for Exercise and Sport Science

The purpose of this paper is to discuss the potential contributions of objective monitoring to the population surveillance of physical activity. Detailed activity and sedentary profiles generated from previously collected activity monitor data are presented and examples of data utilization and interpretation are provided through sample case studies. Profiles are presented in various formats to demonstrate the dangers of data misinterpretation when assessing population adherence to physical activity guidelines. Although these examples use accelerometry data, the findings are generalizable to other time-stamped, objectively measured physical activity data (e.g., heart rate monitors, pedometers, GPS, etc.).

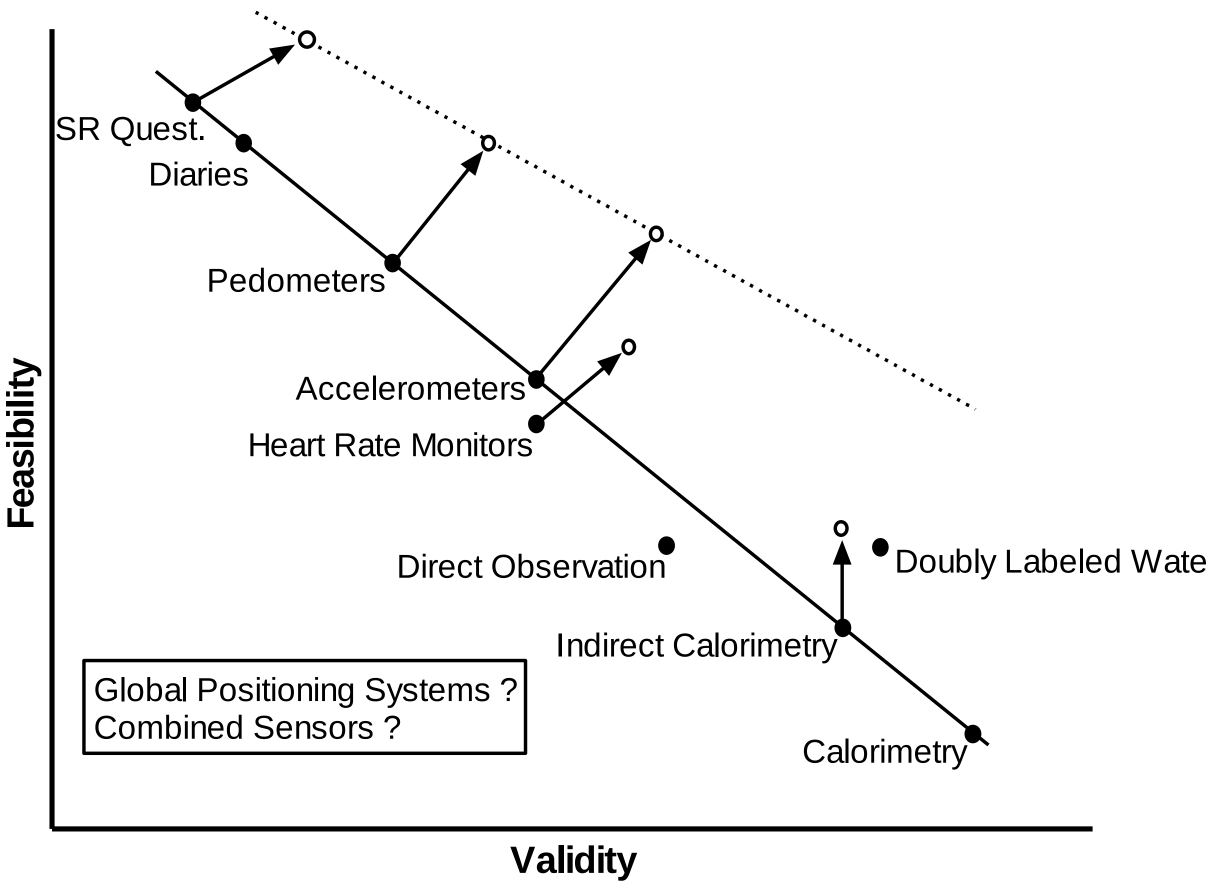


Figure 3.1. Conceptual illustration of the trade-off between validity and feasibility for researchers using a variety physical activity measurement methods (solid line); the relative position of these measurement methods may change as technology and methodologies evolve (dotted line), possibly improving the validity and/or feasibility.
Note: As new technologies emerge their position on the continuum must be established based on research results (e.g., GPS). SR Quest. = Self-Report Questionnaire

3.2 Population Surveillance of Physical Activity

To date, the population surveillance of physical activity in Canada has relied almost exclusively on questionnaire (i.e., self or proxy-reported) data (Katzmarzyk and Tremblay 2007). These authors highlight the incongruence between national health data, indicating a decline in health status, and current physical activity surveillance data which indicate increased levels of physical activity in the population. Katzmarzyk and Tremblay (2007) suggest that the current surveillance is failing to capture the "true" levels of activity and sedentariness in the population. One possible explanation is that many of the questionnaires currently employed measure only one aspect / context of activity, leisure-time physical activity; this accounts for a relatively small proportion of daily energy expenditure (Tremblay et al. 2007b). This limitation of data is evident in information from other countries as well (Troiano et al. 2001). A second explanation is that over time, the population has increasingly tended to over-report socially desirable health behaviours, including physical activity. As a result of these limitations, the authors call for a more robust physical activity and sedentary behaviour surveillance system.

Current physical activity surveillance utilizes self-report questionnaires to determine the proportion of a population that achieves physical activity guidelines based on epidemiological evidence informed by self-report measures of physical activity. However, as physical activity epidemiology evolves, and objective monitoring techniques become commonplace, there is increased likelihood of data misinterpretation, since the guidelines and monitoring procedures are based on differing methodologies. Therefore, it is important to understand fully objective, time-stamped physical activity monitors and the physical activity and sedentary profiling opportunities that they provide. The detailed information obtained by these techniques allows a more comprehensive assessment of the relationships between physical activity and health.

Studies by Rowlands et al. (2000) and Ness et al. (2007) highlight the fact that the relationship between children's physical activity and adiposity is strengthened when objective monitors are used rather than questionnaires. Evidence is mounting (Bassett, Jr. et al. 2000; Epstein et al. 1996; Janz et al. 2004) that studies using activity monitors rather than questionnaires are more likely to detect significant and meaningful associations between physical activity and a variety of health outcomes (Janz 2006). The ability of activity monitors to assess frequency, intensity and duration with extended real time recording allows investigators to examine questions that cannot be answered from questionnaire data. For example, which dimension(s) of physical activity (i.e., frequency, intensity, duration, mode) are important for a particular health outcome and how much activity (i.e., what dose) is necessary to have a beneficial effect (Wareham and Rennie 1998).

Janz (2006) asserted that the most important contribution of activity monitors is their ability to measure routine, intermittent, moderate intensity activities such as walking. It seems intuitive that physical activity of this nature is less memorable and therefore more likely to be underestimated by self-report questionnaires. This is particularly important, as many national and international guidelines promote the daily accumulation of short bouts of moderate intensity physical activity.

3.3 Physical Activity and Sedentary Profiling

3.3.1 Data Reduction and Analysis

The wealth of information provided by objective monitors makes them invaluable in understanding the complex nature of physical activity behaviour. However, data mining is a challenge that accompanies such high resolution data. Fortunately, researchers and manufactures alike are beginning to develop custom and commercially available software to simplify data analysis. Custom software (Esliger et al. 2005) designed by our research team generates a detailed activity profile from seven days of minute-by-minute accelerometry (Figure 3.2; Tables 3.2 and 3.3). Summary variables detailing the frequency, intensity, and duration of physical activity are generated and combined to provide a detailed profile of overall behaviour.

3.3.2 Amount and Intensity of Physical Activity

An important first step in objective analysis is to summarize the raw data. Total and average counts per minute are important accelerometer outcome variables, because they indicate, respectively, the aggregate amount and the intensity of physical activity. However, because counts are tallied in proprietary, manufacturer-specific units, they only allow the comparison of data among similar accelerometer models**.** After obtaining the raw count data, most users convert the arbitrary score into more physiologically relevant units, usually based on energy expended in unit time. In order to calculate the time spent in physical activity, some form of count to intensity (i.e., energy expenditure) prediction equation must be used. However, the issue is complicated by the introduction of several differing cut-point ranges (Hendelman et al. 2000; Puyau et al. 2002; Swartz et al. 2000; Trost et al. 2000) which yield markedly different interpretations of the same data (Strath et al. 2003). A discussion of appropriate cut-points is beyond the scope of this paper; however the lack of consensus, both within and between accelerometer models, remains a major barrier to data interpretation.

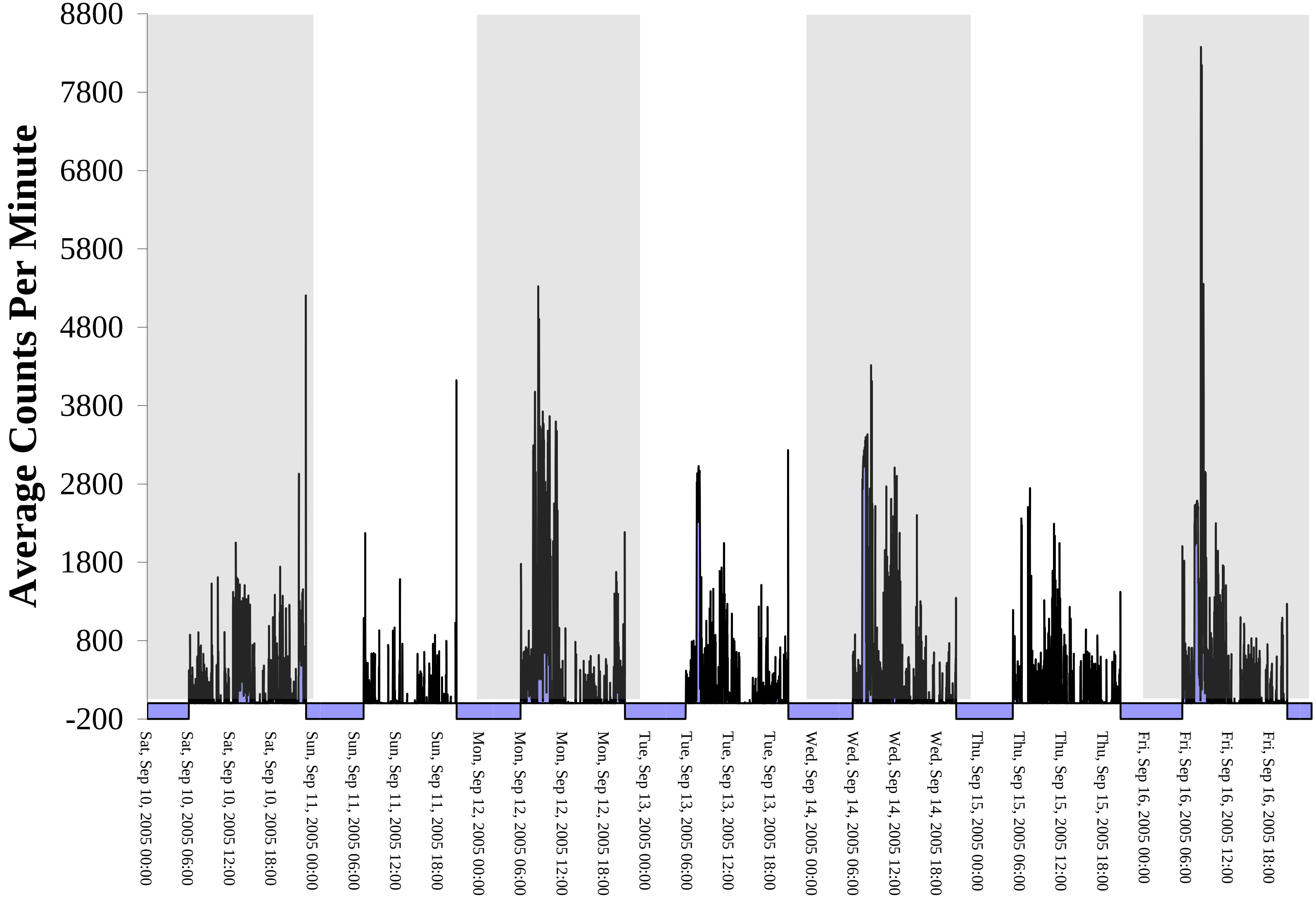


Figure 3.2. Seven day, minute-by-minute activity graph illustrating the intensity of activity over time.
Note: In an effort to facilitate comprehension, each 24 hour period is shaded dark and/or light, sleep time is given a value of -200, and days are labelled in 6 hour segments.

Table 3.2. Sample of a comprehensive physical activity profile.

PHYSICAL ACTIVITY PROFILE

Subject	Gender	Age	Accelerometer Model	Epoch	Days of Monitoring	Location of Monitoring	Monitoring Date
Jim Socks	Male	10	Actigraph 7164	1 minute	7	Latitude: 43° 58' N Longitude: 80° 45' W	Sept. 18-24, 2007

	Weekly Total	**Daily Average**	**Weekday Average**	**Weekend Day Average**	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Amount of Physical Activity											
Counts (x 1000)	**2865**	**409**	**424**	**373**	302	436	566	365	451	396	349
Average Counts/Minute[1]	**459**	**516**	**523**	**498**	394	541	705	465	509	579	418
Light Minutes (<3 METs)	**4560**	**651**	**665**	**618**	675	659	610	658	722	515	721
Moderate Minutes (3.00-5.99 METs)	**958**	**137**	**136**	**139**	87	136	174	126	157	166	112
Hard Minutes (6.00-8.99 METs)	**45**	**6.43**	**8**	**2.5**	5	13	14	2	6	2	3
Very Hard Minutes (9+ METs)	**5**	**0.71**	**1**	**0**	0	0	5	0	0	0	0
Vigorous Minutes (6+ METs)	**50**	**7.14**	**9**	**2.5**	5	13	19	2	6	2	3
MVPA Minutes (3+ METs)	**1008**	**144**	**145**	**142**	92	149	193	128	163	168	115
Accumulation of Physical Activity (MVPA)											
How Sporadic (<10 continuous) Minutes	**750**	**107**	**107**	**109**	80	113	132	128	80	132	85
Number of Sporadic Bouts	**383**	**54.7**	**52.8**	**59.5**	36	52	56	70	50	70	49
Average Minutes/Sporadic Bout	**2.0**	**2.0**	**2.0**	**1.8**	2.2	2.2	2.4	1.8	1.6	1.9	1.7
[2]Short Bout (10-19 continuous) Minutes	**186**	**26.6**	**24**	**33**	12	36	34	0	38	36	30
Number of Short Bouts	**15**	**2.1**	**2.0**	**2.5**	1	3	3	0	3	3	2
Average Minutes/Short Bout	**12.4**	**10.7**	**9.6**	**13.5**	12.0	12.0	11.3	0.0	12.7	12.0	15.0
[3]Long Bout (20+ continuous) Minutes	**72**	**10.3**	**14.4**	**0**	0	0	27	0	45	0	0
Number of Long Bouts	**3**	**0.4**	**0.6**	**0**	0	0	1	0	2	0	0
Average Minutes/Long Bout	**24.0**	**7.1**	**9.9**	**0**	0.0	0.0	27.0	0.0	22.5	0.0	0.0
Short & Long Bout (10+ continuous) Minutes	**258**	**36.9**	**38.4**	**33**	12	36	61	0	83	36	30

When	Early Morning (0600-0830)	**17**	**2.4**	**3.4**	**0.0**	3	4	2	6	2	0	0
	Morning Commute (0830-0900)	**59**	**8.4**	**11.2**	**1.5**	13	5	9	16	13	3	0
	In School (0900-1500)	**437**	**62.4**	**63.2**	**60.5**	33	61	93	50	79	78	43
	Recess (1015-1030)	**42**	**6.0**	**4.8**	**9.0**	4	6	3	3	8	11	7
	Lunch (1200-1300)	**167**	**23.9**	**26.6**	**17.0**	23	47	28	19	16	12	22
	After School (1500-2100)	**286**	**40.9**	**35.8**	**53.5**	16	26	58	34	45	64	43
	Late Night (2100-0000)	**0**	**0.0**	**0.0**	**0.0**	0	0	0	0	0	0	0

[1]Average counts/minute were calculated based on wear minutes only (i.e., sleep minutes were excluded); MVPA = moderate and vigorous physical activity; [2]allowing one minute <3 METs; [3]allowing 2 minutes <3 MET
Note: variables outlining *When* MVPA is accumulated are based on theoretical times of the events listed

Table 3.3. Sample of a comprehensive sedentary behaviour profile.

SEDENTARY BEHAVIOUR PROFILE							
Subject	**Gender**	**Age**	**Accelerometer Model**	**Epoch**	**Days of Monitoring**	**Location of Monitoring**	**Monitoring Date**
Jane Go	Female	10	Actical	15 second	7	Latitude: 53° 10' N Longitude: 106° 43' W	Jan. 16-22, 2007

	Weekly Total	**Daily Average**	**Weekday Average**	**Weekend Day Average**	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Amount of Sedentary Time											
Sleep Hours	**79.1**	**11.3**	**11.3**	**11.2**	10.9	11.6	10.1	12.3	11.9	8.6	13.9
Sedentary Minutes (PAR<1.5)	**3024**	**432**	**432**	**432**	490	474	443	407	345	507	358
Light Minutes (PAR 1.5-2.99)	**4189**	**598**	**603**	**587**	652	603	642	582	537	679	495
Accumulation of Sedentariness											
How Sporadic (<10 continuous) Minutes	**1272**	**182**	**183**	**178**	146	137	221	187	224	175	182
Number of Sporadic Bouts	**1269**	**181**	**180**	**185**	154	129	199	195	222	202	168
Average Minutes/Sporadic Bout	**1.0**	**1.0**	**1.0**	**1.0**	0.9	1.1	1.1	1.0	1.0	0.9	1.1
[1]Short Bout (10-19 continuous) Minutes	**655**	**94**	**100**	**78**	181	55	76	115	73	101	55
Number of Short Bouts	**49**	**7**	**8**	**6**	14	4	6	8	6	7	4
Average Minutes/Short Bout	**13.4**	**13.4**	**13.2**	**14.1**	12.9	13.8	12.7	14.3	12.1	14.4	13.8
[2]Long Bout (20+ continuous) Minutes	**1097**	**157**	**149**	**176**	163	282	146	106	49	231	121
Number of Long Bouts	**34**	**5**	**5**	**6**	5	8	4	4	2	7	4
Average Minutes/Long Bout	**32.3**	**31.2**	**31.0**	**31.6**	32.6	35.3	36.4	26.4	24.4	33.0	30.2
Short & Long Bout (10+ continuous) Minutes	**1752**	**250**	**249**	**254**	343	337	222	220	121	332	176
When AM Commute (8:00-8:45AM)	**76**	**11**	**13**	**5**	22	10	8	6	22	9	0
Morning Recess (10:30-10:45AM)	**24**	**3**	**5**	**0**	14	4	1	5	0	0	0
Lunch Time (Noon-1:00PM)	**188**	**27**	**26**	**30**	48	30	14	17	21	22	37
PM Commute (3:30-4:15PM)	**144**	**21**	**15**	**34**	4	15	15	28	14	37	32

PAR = physical activity ratio (based on cut-points by (Puyau et al. 2004); [1]allowing one minute with a PAR ≥1.5; [2]allowing 2 minutes with a PAR ≥1.5; Note: variables outlining *When* sedentary time is accumulated are based on theoretical times of the events listed

Despite their limitations, prediction equations are important in delineating the number of accelerometer counts per epoch corresponding to a given category of physical activity (e.g., light, moderate, vigorous). This allows an easy calculation of the time spent on physical activity, cited as one of the most relevant variables for public health research because of its direct link to current physical activity recommendations (Welk 2002). Many physical activity guidelines adjust the recommended duration of activity based on intensity (Hardman 2001). For example, Canada's Physical Activity Guide for Adults recommends 60 minutes of light physical activity daily, and as you progress, 30 minutes of moderate to vigorous physical activity on four or more days a week (Health Canada and the Canadian Society for Exercise Physiology 1998). However, as described by Lee (2007), in some populations fitness (used as a surrogate for health) can be improved even with modest doses of physical activity (i.e., approximately 50% of the current guideline of 150 minutes/week) (Church et al. 2007).

3.3.3 Importance of the Collection Period

The time-stamped feature of objective data allows not only a weekly summary, but also a weekday versus weekend day or even a day-by-day summary of outcome variables. This has important implications, as most physical activity guidelines are based on a single day (e.g., 30 minutes of moderate-to-vigorous physical activity (MVPA) per day), yet for many people, behaviour follows a weekly cycle. Measuring for periods of less than 7 days can complicate the assessment of guideline compliance (Esliger et al. 2005). For example, a study participant could accumulate 210 minutes of MVPA through weekend participation in organized sport (i.e., a weekend warrior (Kruger et al. 2007; Lee et al. 2004)). If their average MVPA per day is calculated over the course of an otherwise inactive week, they will appear to have been active for

30 minutes per day. In this example the active weekend days, when averaged on a per day basis, provides a deceptive description of daily physical activity. Figure 3.3 illustrates the problem of using averages when assessing guideline compliance. Similar issues have been demonstrated using self-report measures of physical activity (Sarkin et al. 2000).

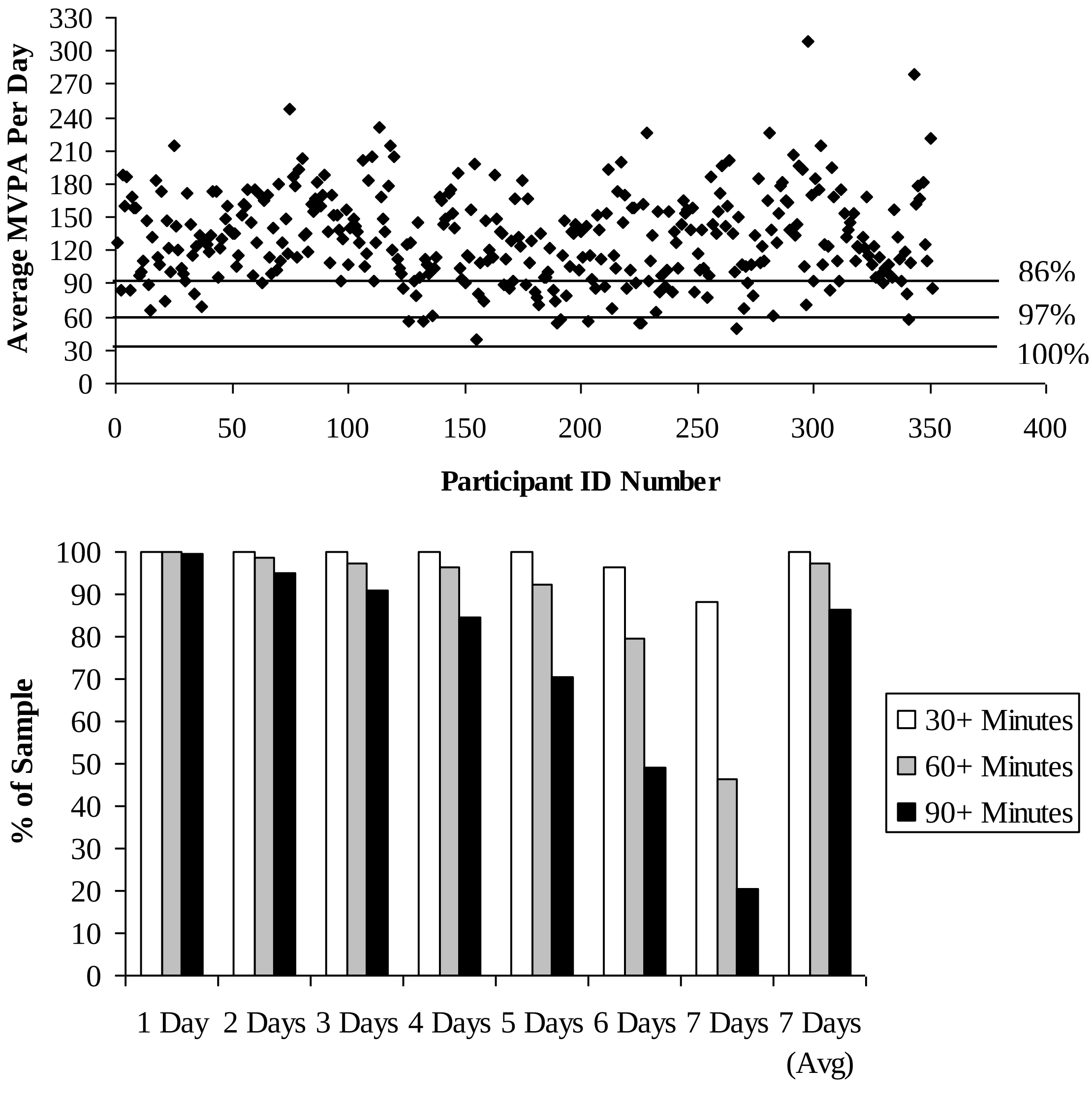


Figure 3.3. Proportion of youths (n = 351) meeting the physical activity guidelines of an average of 30, 60, and 90 or more minutes of MVPA per day [using every minute] (Top); Proportion of youths (n = 351) meeting physical activity guidelines when using *daily* activity requirements of 30, 60, and 90 or more minutes of MVPA [using every minute].
Note. MVPA = moderate and vigorous physical activity (3 + METs)

3.3.4 How Physical Activity is Accumulated

The concept of fractionalization is important, as health benefits may be conferred based on the accumulation of multiple short bouts of physical activity (Hardman 2001). The notion that "every little bit counts" has been incorporated, among other places, into Canada's physical activity guide for adults; this states that activity can be accumulated in bouts of 10 or more minutes (Health Canada and the Canadian Society for Exercise Physiology 1998). At face value, this implies that physical activity bouts of <10 minutes do not "count" towards meeting the guidelines. This is an important point. Figure 3.4 and Table 3.2 illustrate the fact that the bulk of MVPA (at least in children) is accumulated in sporadic bouts lasting less than 10 minutes and therefore would not count towards meeting the guidelines. A correct assessment of guideline compliance should exclude sporadic minutes of MVPA and require compliance on most (5 or more) days of the week (Figure 3.5). The varying proportion of people who meet various physical activity guidelines is highlighted by contrasting Figures 3.3 and 3.5; and the range is from 1-100%! However, the hypothesis that a minimum duration of physical activity (i.e., bouts of >10 minutes) was needed to achieve health benefits was based on self-report data, which is unlikely to reflect less memorable, sporadic/incidental physical activity. Evidence is mounting that underscores the contribution of incidental (i.e., non-purposeful) physical activity to maintaining energy balance and preserving health (Matthews et al. 2007; Tremblay et al. 2007b). With this in mind, many custom programmes (the present one included) incorporate user-defined options for dividing physical activity data into bouts; this allows the user to choose the bout duration for a given intensity of activity. However, because data indicating what should constitute a minimum bout of activity are lacking, it may be prudent to choose analysis options that generate a complete listing of all bout durations. Activity variables of this nature, when linked with health outcome data, could then be used to inform future research.

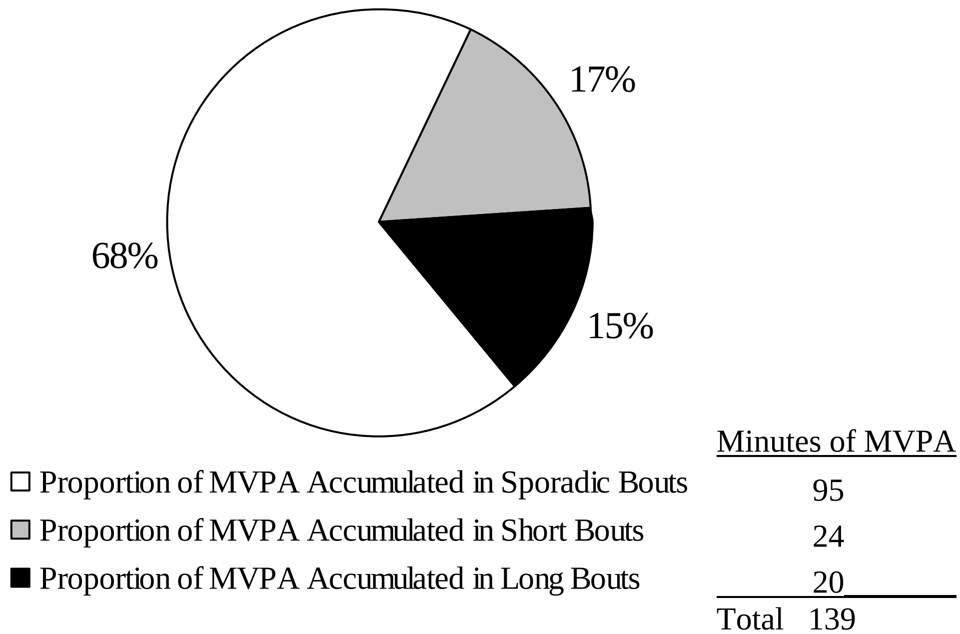
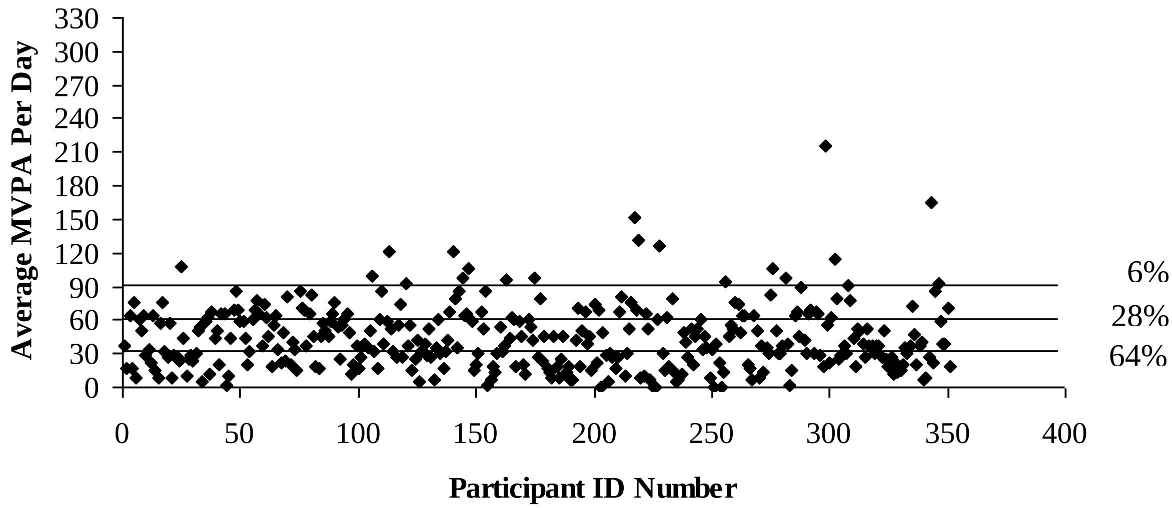


Figure 3.4. Proportion of MVPA accumulated in sporadic bouts (1-9 minutes), short bouts (10-19 minutes), and long bouts (20+ minutes) in a sample (n=351) of youths.
Note. MVPA = moderate and vigorous physical activity (3 + METs)

3.3.5 When Physical Activity is Accumulated

The outcome variables that describe when physical activity is accumulated are also important. Whether one performs more physical activity through the week as opposed to the weekend may provide insight into the context of the activity (e.g., is it occupational, leisure-time or transportation-related physical activity). Also, the ability to summarize data over user-defined intervals allows the researcher to determine particularly active and/or inactive times; this provides insight to reaffirm, or to encourage a change in behaviour. For example, the child in

Table 3.2 has much more physical activity in the 6 hour period at school than in the 6 hour period after school, identifying areas for improvement or intervention.



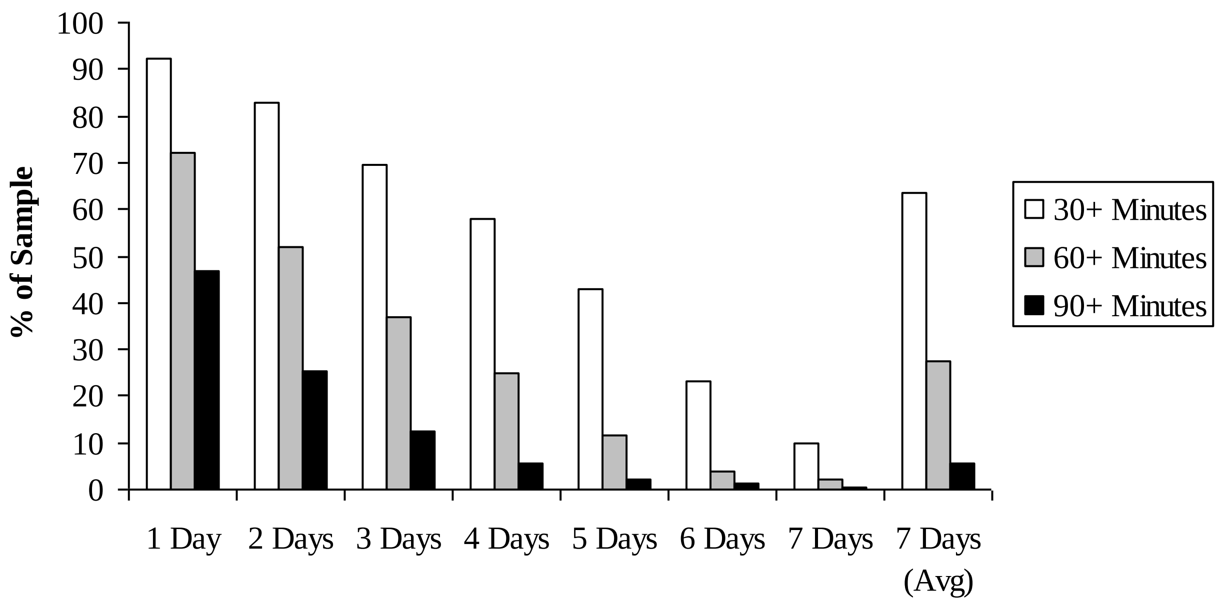


Figure 3.5. Proportion of youths (n = 351) meeting the physical activity guidelines of an average of 30, 60, and 90 or more minutes of MVPA per day in bouts of ≥10 minutes (Top); Proportion of youths (n = 351) meeting physical activity guidelines when using *daily* activity requirements of 30, 60, and 90 or more minutes of MVPA *in bouts of ≥10 minutes*.
Note. MVPA = moderate and vigorous physical activity (3 + METs)

3.3.6 Measuring Sedentary Behaviour

Sedentary variables have become increasingly important in the face of decreasing lifestyle-embedded physical activity (Tremblay et al. 2005a). Sedentary pursuits (e.g., TV viewing) and physical activity are independently associated with health (e.g., metabolic risk in children) (Ekelund et al. 2006), and some nations have already incorporated sedentary time recommendations into their physical activity guidelines (Health Canada and the Canadian Society for Exercise Physiology 2002a; Health Canada and the Canadian Society for Exercise Physiology 2002b). Just what index of sedentary behaviour (e.g., time spent watching television, other screen-time pursuits, time spent sitting etc.) is most informative remains unknown; however, sedentary pursuits should be limited (e.g. the Canadian Pediatric Society (Canadian Pediatric Society Psychosocial Pediatrics Committee 2003) recommends limiting the TV watching of school-aged youth to <2 hours per day). Increased awareness that sedentary behaviours negatively impact health has led to changes in how sedentary behaviours are measured. Many early questionnaires simply used the absence of physical activity as a measure of sedentariness, but contemporary questionnaires try to determine the nature of sedentary behaviours (Gordon-Larsen et al. 2004). Increasingly, activity monitors are being recognized for their ability to provide objective, time-stamped data on how long a person is inactive (Esliger et al. 2005).

Table 3.3 provides an example of a sedentary behaviour profile that can be generated from accelerometer data. Behavioural and environmental approaches to reducing sedentariness are not necessarily identical to those designed to increase physical activity. The resolution and categorization of data realized through prolonged, time-stamped objective monitoring allows a richer profiling; this can improve assessment of interventions and allow new areas of study. For example, although a school-based intervention designed to reduce prolonged sedentary or inactive behaviour may fail to demonstrate increases in self-reported physical activity, or minutes of MVPA as measured by accelerometry, a group sedentary behaviour profile, similar to that in Table 3.3 could demonstrate reductions in measures of sedentariness or a shift of totally sedentary minutes (Physical Activity Ratio (PAR) <1.5) towards minutes of light activity (PAR 1.5-2.99). Just as health benefits may accrue from the accumulation of MVPA, health risks may arise from the accumulation of significant periods of sedentary time (Table 3.3). Again, the detail inherent in time-stamped, objective physical activity monitoring allows this often ignored portion of the health continuum (i.e., inactivity) to be assessed comprehensively (Figure 3.6).

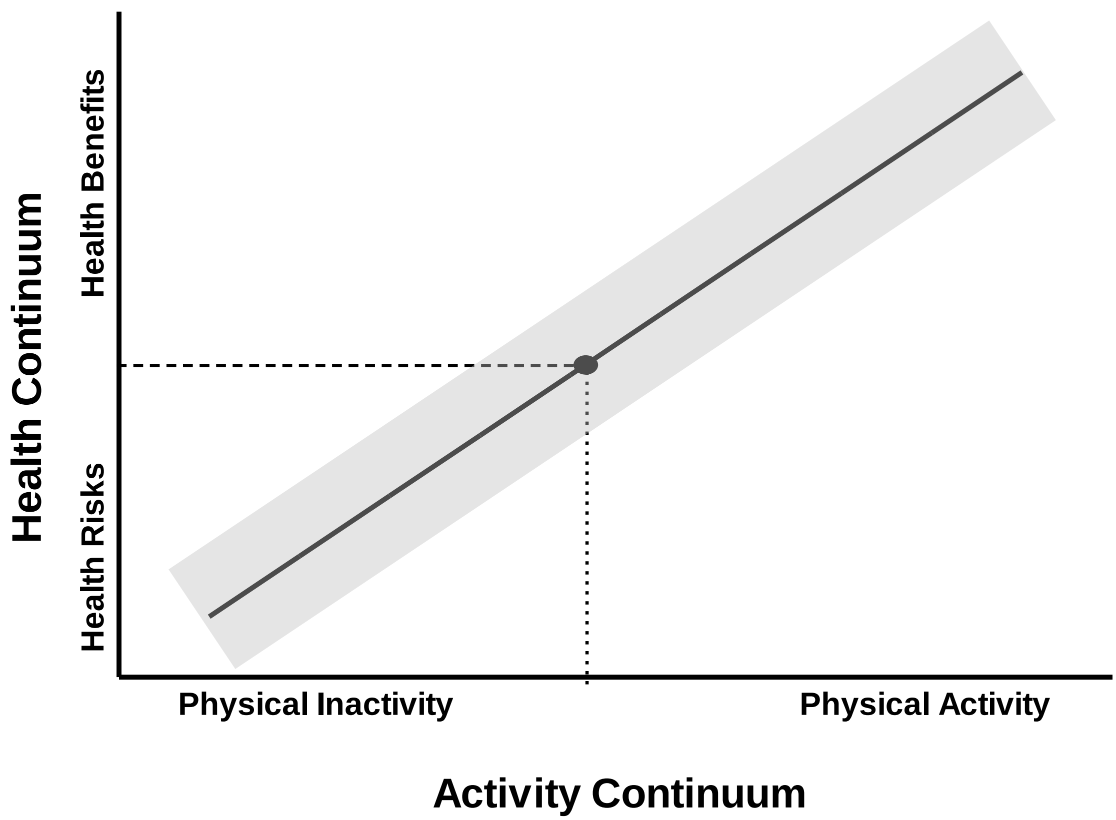


Figure 3.6. Conceptual illustration of the relationship between physical activity and health risks and benefits. As an individual alters their activity level above or below activity homeostasis (i.e., their normal level of activity; dotted line) their health status adapts accordingly.
Note: The shaded section represents the variability in the health outcome response to a given exposure (i.e., physical activity / inactivity). This variability can be attributed to differences in how much, how, and when the physical activity / inactivity is accumulated and/or differences in the health outcome under study.

Canada's Physical Activity Guides for Children (2002a) and Youth (2002b) recommend:

- to increase the time currently spent on physical activity by a total of at least 30 minutes more per day.
- to reduce "non-active" time spent on TV, video, computer games and surfing the internet, starting with at least 30 minutes less per day.
- the 30 minutes more of physical activity can be accumulated in bouts as short as 5 or 10 minutes.
- children and youth should increase activity progressively until they reach at least 90 minutes of daily physical activity.

These child and youth guides are very progressive, taking the explicit approach of recommending increased physical activity and decreased sedentariness. Using the physical activity and sedentary profiling possible with accelerometer data, progress towards achieving Canada's Physical Activity Guidelines can be monitored comprehensively and accurately.

3.4 Future Research

Unfortunately, many objective monitors cannot provide information on mode and/or context of physical activity and therefore require supplementary information to assess these dimensions (usually obtained via questionnaire or diary). However, initiatives are underway to recognize patterns in accelerometer data that may predict specific modes of physical activity (e.g., walking, running, stair climbing) (Pober et al. 2006). Additionally, the advent of multi-sensor devices that combine measurements of heart rate, skin temperature, step counts, acceleration, body position, ventilation rate, GPS, etc. show promise in capturing even more information about physical activity and sedentary behaviour. For example, combining accelerometers with inclinometers, Levine and colleagues (2005) found that, on average, obese individuals were seated 2 hours longer per day than lean individuals. They also showed that the pattern of sedentary behaviour was unaltered even when these individuals gained or lost weight, suggesting that posture allocation may be biologically determined. Future research is required to understand and refine the data that emerges from increasingly sophisticated monitoring devices and to interpret these data in the context of existing physical activity guidelines. Research is also required to understand more subtle differences in habitual physical activity across gender, age, ethnicity, immigrant status, marital status, geographic location and other demographic indicators.

The number of continuous variables generated and displayed in Tables 3.2 and 3.3 give an indication of the potential for further exploring the relationship between physical activity and health. In addition to investigating relationships among health indicators and dimensions of physical activity (e.g., frequency, intensity and duration), detailed profiles permit us to study:

- whether certain patterns of activity accumulation are associated with better outcomes
    - morning vs. afternoon vs. evening
    - sporadic vs. short vs. long-term
    - every other day vs. sequential days vs. "weekend warrior" activity pattern
- the relative usefulness of indices of sedentariness compared to activity
- the importance of variability in activity (or sedentary time)
    - between days
    - between weekdays and weekend days

    - within days, but between patterns of activity accumulation (sporadic, short, long)
    - within days, but between times (morning, afternoon, evening)
- the variability in findings when higher or lower resolution epochs are used
- how the health benefits of physical activity are accumulated, and whether this accumulation varies with age, gender, occupation etc.

Results from research as described above has the potential to lead to better informed and more refined physical activity guidelines for Canadians.

3.5 Summary

Growing public health concerns about inadequate physical activity and excessive sedentariness are creating demands for improved surveillance of these behaviours. Objective physical activity monitors are being used more frequently to address this demand. These devices allow for a much more detailed profiling of physical activity and sedentary behaviour if the data collected are used to their full potential. However, care must be taken to ensure that findings are interpreted correctly, as there is opportunity for misleading and/or opportunistic data reporting. This "next generation" of physical activity and sedentary indices creates enormous research potential; ultimately, this can further inform the development, customization and modification of physical activity guidelines for Canadians.

3.6 Acknowledgements

This project was supported by the Public Health Agency of Canada. The leadership and administrative assistance was provided by the Canadian Society for Exercise Physiology. The authors would like to thank Eric Finley for his technical assistance with accelerometer data reduction programming.

Chapter 4: Study 3

Title: **Physical activity profile of Old Order Amish, Mennonite, and contemporary children**

Study 3 has been published as an original investigation article in a peer-reviewed journal (Esliger et al. 2010). With the exception of the some minor wording and/or format changes that were necessary for the conversion to graduate thesis format, it is presented in its submitted form. The introduction section below may repeat key aspects of the review of literature directly pertinent to the purpose of the study.

4.1 Introduction

Recent 7-day pedometer data from a nationally representative sample of 6,000 Canadian children and youth aged 5-19 years indicate that 73-91% do not accumulate sufficient daily steps (Cameron et al. 2007). Likewise, recent National Health and Nutrition Examination Survey (NHANES) data show that 58% of American children aged 6-11 and 92% of adolescents aged 12-19 are not meeting the recommended 60 minutes per day of physical activity (Troiano et al. 2008). Although these data suggest that many children and youth are inactive, they do not allow us to determine if this was always the case or if physical activity has declined over time. Knowing how physically active children were when childhood obesity was rare may offer insight into obesity treatment and/or prevention. Unfortunately, longitudinal physical activity data on nationally representative samples of children and adolescents are lacking (Katzmarzyk et al. 2008). However, data from questionnaire and time use studies may provide some insight into physical activity trends. For example, Canadian data show no change in leisure-time physical activity from 1981-1998 (Eisenmann et al. 2004). These data are in line with more recent U.S data from the National Youth Risk Behavior Surveys that found no significant temporal trends in physical activity and sedentary behaviour between 1999 and 2005 (Katzmarzyk et al. 2008).

In contrast to these trend data, evidence suggests that U.S. children and youth walk and cycle less for transportation with active trips to school decreasing from 20.2% in 1977 to 12.5% in 2001 (Sturm 2005b). Further, U.S. time use data suggest that increased time spent in school, child care, studying, and reading have substantially decreased play and discretionary time from 1981 to 1997 (Sturm 2005a). However, these conflicting data are based on proxy ecological evidence that does not take into account temporal changes in a certain domain (e.g., reductions in active commuting) which may be counter-balanced by opposing changes in another domain (e.g., increases in sports participation) (Stamatakis et al. 2007). Moreover, it is generally felt that the major impact of technology on sedentary behaviour was reasonably complete by the 1950s due to the phasing out of heavy manual labour (Haskell 1996). Although further reductions in physical activity were expected due to advances in computer and communication technology, it was believed they would be much more subtle. Until more robust measures of physical activity are integrated into public health surveillance systems, our ability to monitor trends accurately will continue to be severely limited (Katzmarzyk and Tremblay 2007).

In an effort to overcome the gap in historical trend data, Tremblay et al. (2005b) developed a unique model to assess the impact of modernity on activity levels in children. The authors reasoned that some cultures may preserve the inherently active lifestyle of earlier generations that preceded erosions to leisure-time and occupational physical activity and the childhood obesity epidemic. Their data show that Old Order Mennonite (OOM) children are leaner, stronger and more active than contemporary-living children from both rural and urban communities. Extending the model to look further back in time, Bassett et al. (2007) found that Old Order Amish (OOA) children take more steps per day and have lower rates of overweight and obesity than contemporary-living children. Although much has been learned about the physical activity of Old Order Amish and Old Order Mennonite children, only the most basic variables have been explored to date (i.e., average moderate to vigorous physical activity (MVPA) per day and average steps per day). While quantitative information is useful for informing evidence-based physical activity guidelines (i.e., how much physical activity one should do to be healthy), it offers no insights into how one might go about achieving the recommended levels of physical activity (Brawley and Latimer 2007).

To fully understand the quantity and quality of physical activity of these traditional groups, further work is needed to examine their activity patterns (i.e., specific intensities and timing of activity and sedentariness) (Bassett 2008). Therefore, the purpose of this paper was to profile the physical activity and sedentary behaviours of Old Order Amish, Old Order Mennonite, and contemporary-living children as a means of assessing the influence of lifestyle. Hypothesis one was that group differences in physical activity would be evident (i.e., Amish > Mennonite > contemporary-living children). Hypothesis two was that group differences in sedentariness would be evident (i.e., contemporary-living > Mennonite > Amish children). Hypothesis three was that the timing (e.g., time of day and day of the week) of the physical activity of the Amish and Mennonite children would differ from that of the contemporary-living children.

4.2 Methods

The study employed an ex post facto (comparative) design whereby the cause(s) of group differences are assumed despite the lack of an experimental design. An overall sample of 474 children was drawn from four different groups: two living a traditional agrarian lifestyle (OOA and OOM) and two living a mainstream contemporary lifestyle (rural (RSK) and urban (USK)). Details of the Ethics Review process can be found in Appendix B. The sampling procedures differed across the groups as follows: i) OOA: sampled entire population of 81 children (i.e., 100% response rate); ii) OOM: randomized by family from a pre-screened list with a total eligible population of 300 with an achieved response rate of 40%; iii) RSK: self selected volunteers with a total population of 262 children and an achieved response rate of 59%; USK: self selected volunteers with a total population of 178 and an achieved response rate of 62%. As this study is based on secondary data analysis, each sample has been described in detail elsewhere (Bassett 2008; Bassett, Jr. et al. 2007; Tremblay et al. 2005b; Tremblay et al. 2008). Details of the consent process can be found in Appendix C. In brief, the lifestyle of OOA and OOM children emphasizes simplicity and traditional values rather than progress and technology. Ownership of automobiles is not permitted. Farm tractors, telephones, and bicycles, are permitted, however, among the OOM. Farming and various labour trades are the preferred occupation. Children are educated in their own schools and formal education takes place only through to eighth grade. Therefore, we reasoned that the lifestyles of OOA and OOM children would be representative of typical physical activity behaviours of 100 and 60 years ago, respectively. The lifestyles of RSK children are typical of rural towns (population <5000) whereas the lifestyles of USK children are typical of urban centers (population >200,000) in Canada today.

As part of a larger battery of anthropometry and health-related fitness tests (peripheral to the present study), the 8-13 year old children had their height and body mass measured using a Health O Meter 402KL balance beam scale (Health O Meter Inc., Bridgeview, Illinois, United States). The attached height rod served as a stadiometer. The triceps skinfold was measured midway between the shoulder and elbow on the right arm using Harpenden C136 skinfold calipers (British Indicators, West Sussex, England). All anthropometric measures were measured using the same procedures and equipment for all samples.

In the autumn, each child's physical activity was objectively measured for seven consecutive days via accelerometry. All pertinent data collection and analytical procedures related to the accelerometry portion of the study are described in Table 4.1. The raw data were analyzed using custom software KineSoft version 2.0.95 (KineSoft, New Brunswick, Canada) to produce a series of standardized outcome variables similar to the procedures of Esliger et al. (2005) (2007). For a detailed explanation of how KineSoft works, see Appendix D. The main variables of interest were average minutes of sedentary, light, moderate, and vigorous intensity physical activity per day. Because the timing of activity and sedentary behaviour was of interest, the intensity variables were analyzed with the following time period groupings: weekday, weekend day, and hourly. Physical activity was measured using the same procedures and accelerometer model for all samples. In addition to parental consent, each child provided written assent to participate in the study. All procedures were approved by the Institutional Research Ethics Boards of the University of Saskatchewan and University of Tennessee.

4.2.1 Statistical Analyses

One-way ANOVAs were used to test for group differences in chronological age, month of data collection (i.e., seasonality), and accelerometer wear time. Subsequent analyses used MANCOVA models with chronological age and wear time as the covariate to determine group differences in anthropometric variables and physical activity and sedentary variables. Owing to the skewed distribution of the moderate and vigorous physical activity variables, these data were log transformed. All statistical tests were performed on the transformed data; however, in all cases the non-transformed means and standard deviations are presented. Paired samples t-tests were used to determine within group differences in the weekday versus weekend day physical activity variables. The influence of time of day on physical activity and sedentariness was described visually via 24 hour x 7 day area plots for each group. Where appropriate, models used Bonferonni adjustments for post-hoc comparisons and alpha was set at $p<0.05$. All analyses were performed using SPSS for Windows version 15.0 (SPSS Inc., Chicago, IL).

Table 4.1. Accelerometry data collection and analytical procedures.

General Information	
Device	Actigraph
Model	7164
Piezosensor Orientation	Uniaxial
Number of Accelerometers Used	117
Serial Number Range	11672-23880
Average Number of Deployments Per Unit	4 (ranging from 1 to 9)
Pre-deployment Calibration Check	Yes
Technical Variability Tolerance (CV%)	≤5%
Setup Information	
Mode	Counts Only
Epoch	1 Minute
Deployment Method	Delivered and attached by researcher (on day 0)
Location Worn	Right hip at mid clavicular line (via adjustable nylon waist belt)
Requested Days of Wear	7 days (i.e., 10080 epochs) not including day 0
Initialization & Monitor Start Time	Delayed until next day (i.e., day 1 at 06:00)
Wear Instructions	During all *waking hours (except water based activities)
Analytical Decisions	
Sleep Time Appropriation	Continuous zeros indicating the start of sleep time were coded by researchers based on the transition from epochs with normal count data to epochs of continuous zeros. The accelerometer on time at wake up was marked based on the first non-zero epoch after the overnight period (informed by the participant's log sheet).
Valid Day Criteria	10 hours of wear
Valid File	At least 5 of 7 days (with at least 1 weekend day)
Modeling (i.e., imputation) of Missing Data	None

Daylight Saving Time	Files crossing DST in the fall of 2002 were corrected for the repeat hour
Cutpoint Reference(s)	For light, moderate, and vigorous intensity, age-specific cutpoints developed by the Freedson group as published by Trost et al. (2002) were used. The sedentary cutpoint, although not empirically derived, has been published previously by Mattocks et al. (2007).
Sedentary	0-199 counts
Light Intensity	200 counts – 3.99 METs (age specific)
Moderate Intensity	4.0 – 6.99 METs (age specific)
Vigorous Intensity	7+ METs (age specific)

*The start and end of the daily accelerometer wear periods was used as a surrogate for sleep time.

Table 4.2. Characteristics of the study sample.

Variable	OOA	OOM	RSK	USK
Sample location in Canada	Aylmer, ON	Waterloo & Wellington County, ON	Clavet, Colonsay, & Hanley, SK	Saskatoon, SK
Data collection period	Spring 2005	Fall 2002	Fall 2002	Fall 2002
Original sample	79	120	165	110
Failed to initialize/collect	10	0	8	3
Spurious data	1	0	6	0
Not enough wear time	0	0	19	14
Viable sample	68	120	132	93
7 valid days	68 (100%)	120 (100%)	105 (80%)	76 (82%)
6 valid days	-	-	24 (18%)	15 (16%)
5 valid days	-	-	3 (2%)	2 (2%)
Average daily wear minutes (SD)	873 (33)	820 (27)	805 (46)	806 (44)
Average daily non-wear minutes (SD)	567 (33)	620 (27)	635 (46)	634 (44)
Average morning "on" time (SD)	06:38 (0:25)	07:07 (0:26)	08:13 (0:31)	08:30 (0:35)
Average evening "off" time (SD)	21:05 (0:25)	20:49 (0:22)	21:28 (2:11)	22:01 (0:47)

Note: Non-wear (manually coded by the researcher) was used as a surrogate for sleep

4.3 Results

The characteristics of the study sample are displayed by group in Table 4.2. The sample size lost to technical failure of the accelerometers was 13.9, 0.0, 8.5, and 2.7% for the OOA, OOM, RSK, and USK groups respectively. The traditional lifestyle groups were diligent in wearing their accelerometers and recording on/off times on their logs. As a result, the average sample size lost to participant non-compliance (i.e., not wearing the accelerometer for at least 10 hours per day for at least 4 weekdays and 1 weekend day) was 0.0, 0.0, 12.6, and 13.1% for the OOA, OOM, RSK, and USK groups respectively. Impressively, 100% of the OOA and OOM children had 7 days of valid data. All groups exceeded the daily wear time requirement with OOA children having the greatest average amount of wear time (14.5 hours per day) and RSK and USK children having the least (13.4 hours per day). The extra wear time was a result of the 1-2 hour earlier morning wake-up times of the traditional groups and their 30-70 minute earlier bed times.

The descriptive characteristics of the participants are displayed by group in Table 4.3. The samples are sex balanced; however, because the OOM children were older than the other groups, all further analyses controlled for age since it is well established that physical activity declines with age (e.g., a recent study (Nader et al. 2008) convincingly showed physical activity reductions from 9 to 15 years of age). OOA children were shorter than RSK children, weighed less than OOM and RSK children, and had lower BMI and triceps skinfolds than all other groups.

Table 4.3. Descriptive characteristics of study participants; mean (SD) and range.

Variable	OOA	OOM	RSK	USK
N (% female)	68 (44)	120 (45)	132 (57)	93 (54)

Age (yrs)	10.6 (1.74)	11.6 (1.26)*	10.9 (1.20)	11.1 (1.16)
	8.0-13.9	9.1-13.8	8.8-13.2	8.8-13.2
Standing height (cm)	141.0 (11.7)	149.0 (9.3)	146.3 (10.1)†	146.2 (10.3)
	119.0-165.0	124.5-174.5	123.5-169.0	122.0-172.0
Weight (kg)	35.3 (10.2)	44.4 (10.1)†	41.2 (9.7)†	40.6 (9.6)
	20.0-73.3	23.5-70.3	21.4-69.5	22.0-67.8
BMI ($kg \cdot m^{-2}$)	17.2 (2.6)**	19.8 (3.0)	19.0 (2.8)	18.8 (2.7)
	13.4-31.3	13.2-26.7	11.9-26.2	13.9-25.8
Triceps skinfold (mm)	10.8 (4.8)**	16.5 (6.8)	17.7 (7.2)	18.0 (7.5)
	5.0-31.7	6.1-33.0	5.2-39.8	5.5-39.4
Prevalence of overweight (%)	3.0	28.3	23.7	18.3
Prevalence of obesity (%)	1.5	3.3	1.5	1.1

BMI = body mass index; * significantly different from all other groups; ** significantly different from all other groups when controlling for age; †significantly different than OOA when controlling for age; $P<0.05$

4.3.1 Influence of Lifestyle on Physical Activity and Sedentary Behaviour

Support for hypothesis one was evident on weekdays where there were group differences in moderate intensity physical activity (4-6.99 METs) between traditional lifestyle groups and contemporary lifestyle groups (OOA > OOM > USK > RSK; 90, 69, 58, 49 minutes per weekday respectively) (Figure 4.1). On the weekend, the group differences in moderate intensity physical activity persisted between, but not within, lifestyle groups (OOA = OOM > USK = RSK; 55, 54, 36, 40 minutes per weekend day respectively) (Figure 4.2). There was relatively little vigorous physical activity (≥ 7 METs) accumulated on any day of the week. On weekdays OOA children accumulated a greater amount of vigorous physical activity compared to all other groups (Figure 4.1). Although the greater amount of vigorous physical activity in OOM children compared to RSK children was statistically significant, it is unlikely to have biological significance. With even fewer minutes of vigorous physical activity accumulated on the weekend by all groups, it was of little surprise that there were no differences between groups

(Figure 4.2). Likewise, there were no group differences in sedentary behaviours between lifestyle groups on weekdays (Figure 4.1); however, on weekend days the USK children accumulated more sedentary time than any other group and the RSK children were more sedentary than the OOM children (Figure 4.2).

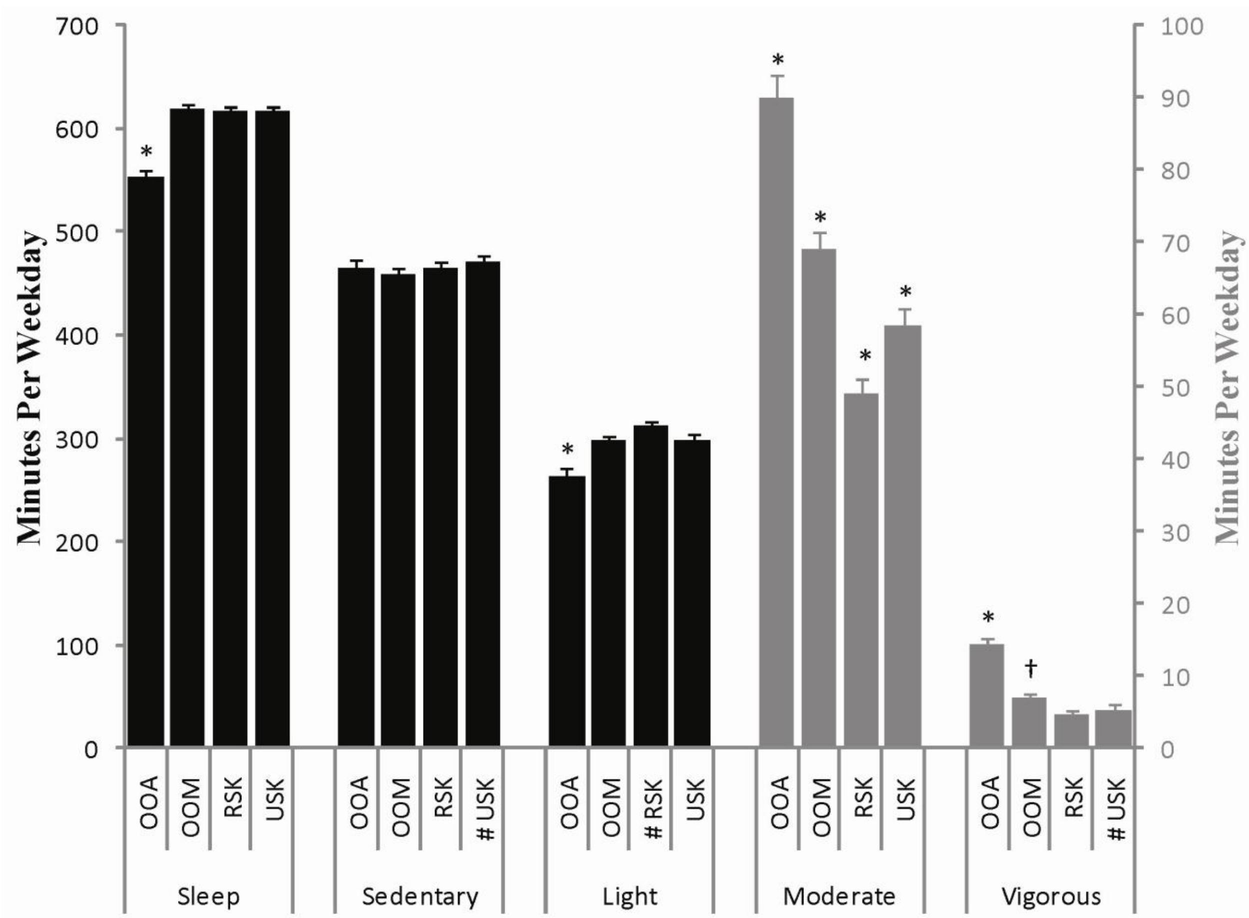


Figure 4.1. Mean minutes per weekday of sleep, sedentary, light, moderate, and vigorous intensity physical activity, by group
*significantly different from all other groups; †significantly different from RSK; # indicates no within group difference between weekday and weekend day on the given variable; $P<0.05$
Notes: i) means are adjusted based on age and wear time covariates; ii) both moderate and vigorous physical activity are scaled according to the secondary y-axis; iii) although statistical analyses were performed on log transformed moderate and vigorous physical activity variables, non-transformed data are presented; iv) error bars represent standard error

4.3.2 Influence of Day of the Week and Time of Day on Physical Activity and Sedentariness

All within group differences between weekday and weekend day physical activity and sedentary time were significant with the exception of the USK group for sedentary time and vigorous physical activity and the RSK group for light activity (Figures 4.1,4.2).

Plotting and visualizing the hourly physical activity behaviours by intensity and group revealed some interesting temporal trends (Figure 4.3). Focusing on school days (i.e., Monday-Friday from 08:00-15:00), it appears that the groups have similar patterns in physical activity and sedentariness (i.e., they have the same activity and sedentary 'hotspots'). Comparing the two peak sedentary hours of the school day (i.e., 09:00-10:00 and 13:00-14:00) showed that OOA and OOM children spent on average, 50 of every 60 minutes during these two, one-hour blocks being sedentary compared to 40 of every 60 minutes for the contemporary children. Although being more sedentary during school hours, the OOA and OOM children were more active overall as evidenced by the higher amounts of moderate physical activity. In fact, both traditional groups had a pronounced tri-modal pattern of moderate physical activity, peaking during the morning commute (08:00-09:00), morning recess (10:00-11:00), and lunch (12:00-13:00) hours (Figure 4.4). Notably, the hour during lunch break was on average the most active for all groups even when compared to free time on evenings and weekends. On average, OOA and OOM children spent 9 of every 60 minutes during these three, one-hour blocks being moderately active (compared to only 5 of every 60 minutes in the RSK and USK children). In fact, with the exception of the peak in moderate physical activity over the lunch break, it was difficult to discern clear peaks during the morning commute and/or the morning recess in the contemporary groups. The hourly contribution of vigorous physical activity was negligible across all groups over these three time periods.

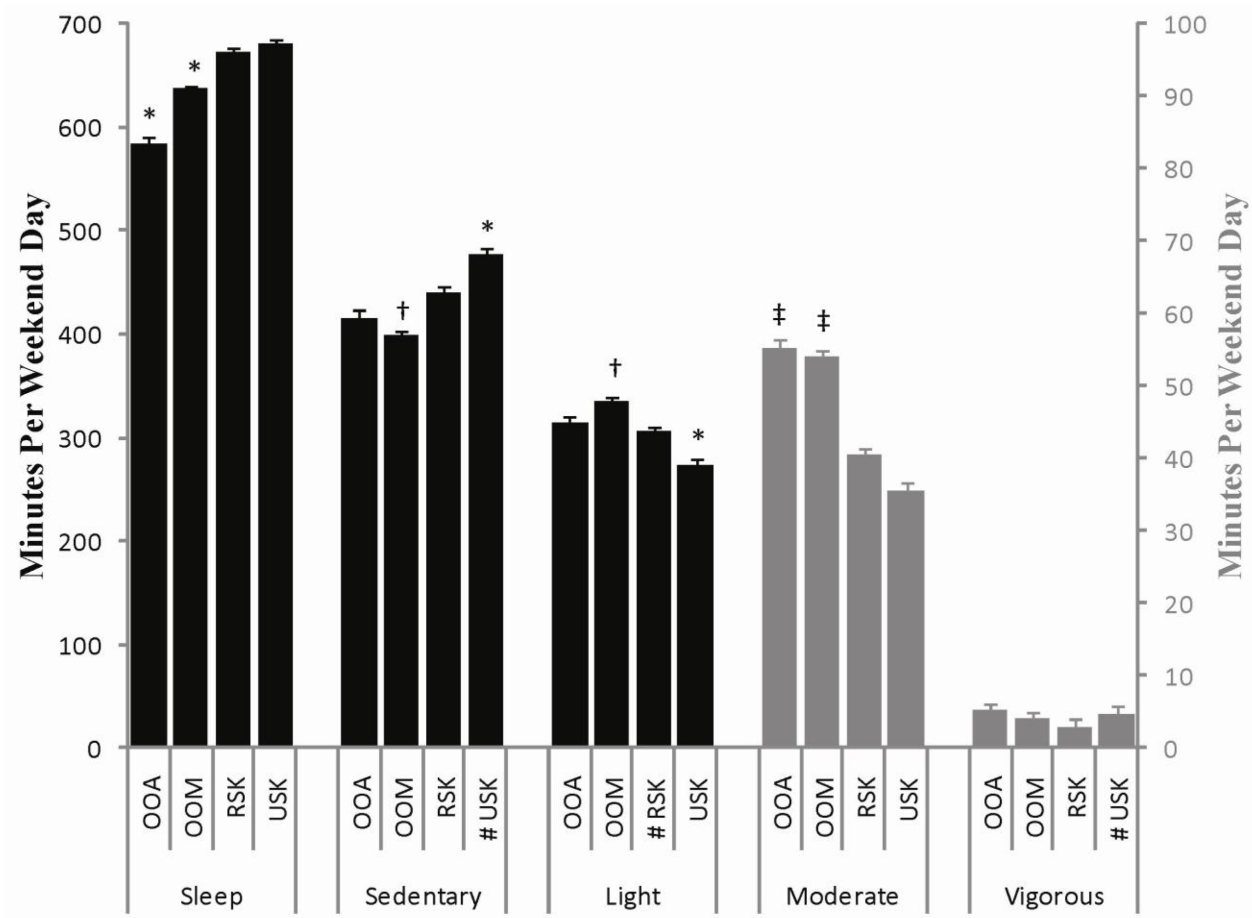


Figure 4.2. Mean minutes per weekend day of sleep, sedentary, light, moderate, and vigorous intensity physical activity, by group
*significantly different from all other groups; †significantly different from RSK; ‡significantly different from RSK and USK; # indicates no within group difference between weekday and weekend day on the given variable; P<0.05
Notes: i) means are adjusted based on age and wear time covariates; ii) both moderate and vigorous physical activity are scaled according to the secondary y-axis; iii) although statistical analyses were performed on log transformed moderate and vigorous physical activity variables, non-transformed data are presented; iv) error bars represent standard error

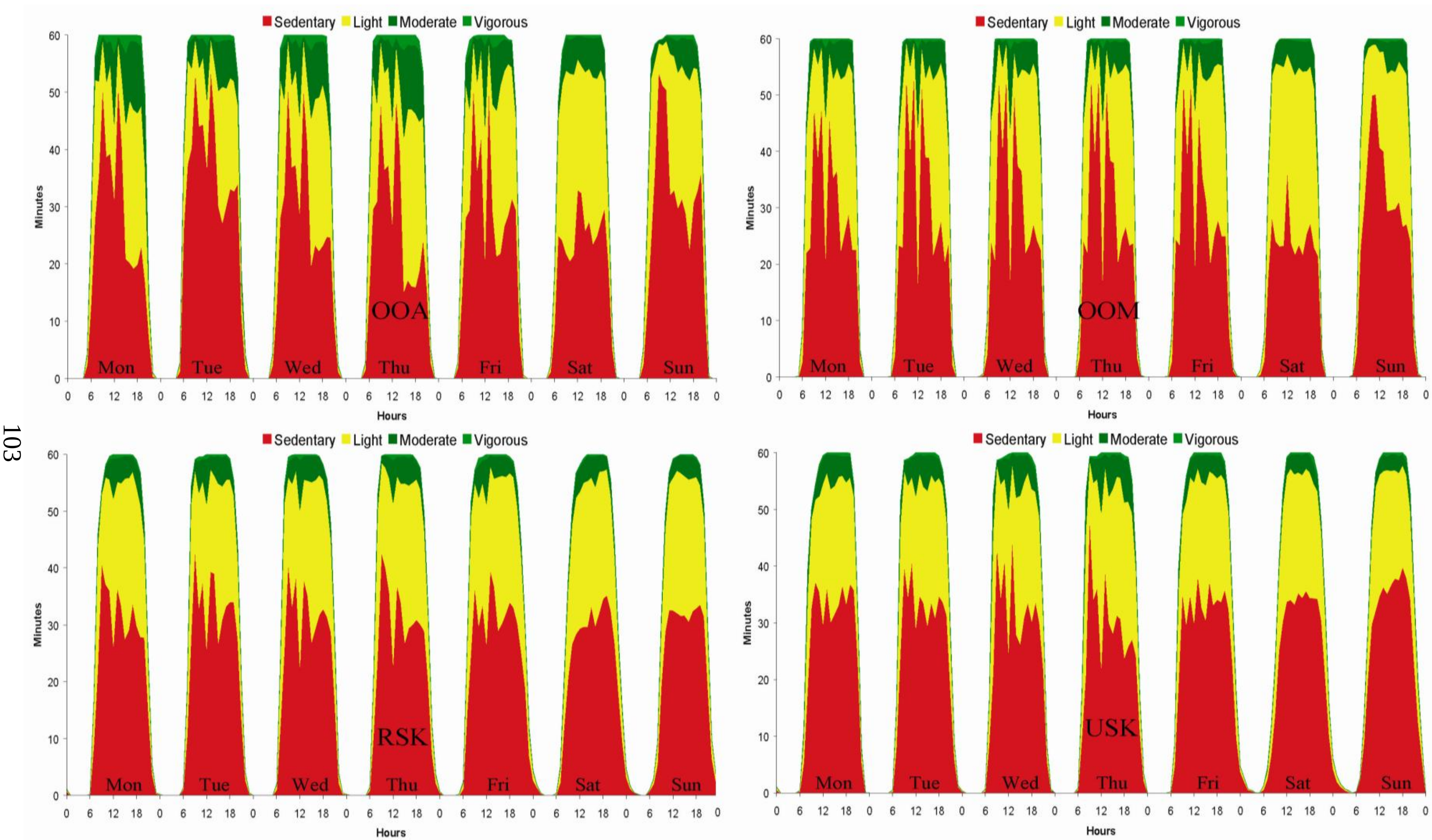


Figure 4.3. Group differences in intensity-specific physical activity profiles (7 days x 24 hours)
Note: White areas of the figure represent sleep time while the coloured areas signify traffic light labelling of physical activity intensity. The sedentary activity is coloured red to give the message to stop the behaviour, light activity is coloured yellow to give the

message to be cautious of too much light activity, and both moderate and vigorous activity are coloured green to give the message that these are positive behaviours.

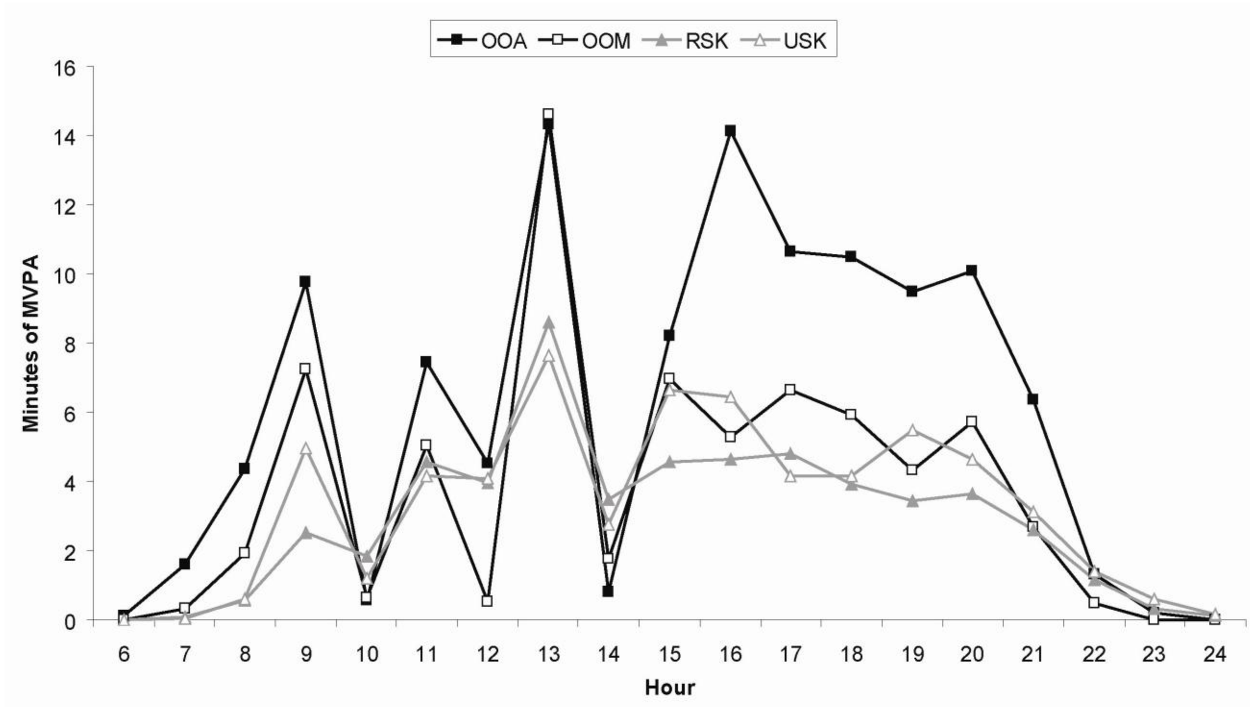


Figure 4.4. Descriptive group differences in weekday moderate to vigorous physical activity (hour x hour)

Compared to the in-school time, OOA and OOM children's out-of-school time (i.e., Monday-Sunday from 15:00-21:00) showed a marked decline in sedentary time and an increase in time spent in moderate physical activity. This favourable shift was less pronounced in the RSK and USK children (Figure 4.3). Compared to in-school time, there was on average, 44% less sedentary time out of school in the OOA and OOM children amounting to 25 of every 60 minutes (27 minutes on weekend days) being spent sedentary during this 6-hour block. However, in the RSK and USK children sedentary time out of school was only 15% lower than in school time, amounting to 31 of every 60 minutes (35 minutes on weekend days) being spent sedentary during this 6-hour block. On weekend days, the RSK and USK children's sedentary time was fairly consistent with roughly half of every hour spent sedentary. Although OOA and OOM children were more active on Saturday, they were more sedentary on Sunday.

Collectively these results support the hypothesis that the groups differ with respect to the day of the week and the time of the day they accumulated their physical activity and sedentary time.

4.4 Discussion

The purpose of this study was to determine if differences in the lifestyles of children would be evident in their physical activity behaviour profile (e.g. intensity and timing). In an attempt to provide a ‘window’ to the past, we profiled the physical activity behaviours of Old Order Amish and Mennonite children known to differ in their use of modern conveniences such as labor saving technologies and sedentary, multimedia-based leisure pursuits. Though cross-sectional, these data suggest that contemporary/modern living is associated with lower levels of moderate physical activity compared to lifestyles representative of earlier generations (weekdays: OOA > OOM > USK > RSK; weekend days: OOA = OOM > USK = RSK). It is important to note that the physical activity levels of RSK and USK children (i.e., 51 and 58 minutes of MVPA per day) are comparable to other similarly analyzed datasets (e.g., NHANES, 60 minutes of daily MVPA; (Troiano et al. 2008)). These comparative data imply that the differences between lifestyle groups are a result of OOA and OOM children being more active (i.e., 91 and 71 minutes of MVPA per day), not USK and RSK children being less active than typical children today. The fact that these traditional groups do not participate in organized sports or attend physical education classes suggests that the group differences are likely explained by differences in lifestyle-embedded physical activities such as farm and other manual chores, active commuting, and free play. This explanation seems logical when one considers the substantial contribution that lifestyle-embedded physical activities, also referred to as NEAT (non-exercise activity thermogenesis) (Levine et al. 1999), make towards total daily physical activity energy expenditure (Tremblay et al. 2007b).

Those living a traditional agrarian lifestyle, most notably OOA children, accumulated large amounts of physical activity and met or exceeded most national physical activity guidelines, including on weekdays, Health Canada's (2002a; 2002b) recommendation of ≥90 minutes per day. Therefore, the physical activity and sedentary profiles of OOA and OOM children may be a useful behavioral model for contemporary children to emulate. Perhaps the most remarkable difference between lifestyle groups was the consistently greater amount of physical activity and less time spent sedentary exhibited by the OOA and OOM children compared to the RSK and USK children in their discretionary time. Although the context or mode of this 'extra' physical activity is unknown, detailed information is available with respect to when/how this activity is accumulated. This 'how-to' information is crucial for the development of effective physical activity messages and programs that are necessary to promote healthy behavior change (Brawley and Latimer 2007). For example, data from OOA children highlight the fact that the physical activity gap that exists for contemporary children could be made up by encouraging them to accumulate small amounts of physical activity intermittently throughout the day (e.g., during the morning commute, recess, lunch, after school commute and during the evening). These data, which are in agreement with those recently published by Riddoch and colleagues (2007), show that making small changes in behaviours can add up to significant amounts of daily physical activity.

Living a lifestyle reminiscent of 100 years ago, OOA children accumulated on average 55 minutes more MVPA per weekday and 18 more minutes per weekend day compared to contemporary children. The 'extra' time spent being active in OOA children was significant and likely contributed to their low levels of overweight and obesity (Bassett, Jr. et al. 2007; Tremblay et al. 2008). Unfortunately information about the mode and/or context of the physical activity is unknown; however, it is likely that agricultural chores contributed to the higher activity levels in the OOA and OOM children. Based on conservative estimates (i.e., using 4 $kcal \cdot kg^{-1} \cdot hr^{-1}$), this translates to an activity energy expenditure deficit of 124 kcal per weekday and 51 kcal per weekend day for the contemporary children. All else being equal, if the energy imbalance was maintained over the long term the contemporary children would be at risk of gaining ~5 kg of fat per year (assuming that 7700 kcal leads to an average of 1 kg weight gain as fat). This energy gap is similar to that found by Wang et al. (2006) who suggested that consistent behavioural changes (i.e., reduced energy intake and/or increased energy expenditure) averaging 110 to 165 kcal/day may be sufficient to counterbalance the energy gap in children. Unfortunately, maintaining energy balance in a modern world is difficult since the behavioural processes that evolved in order to ensure our survival are still intact. That is, people still eat when food is available and 'rest' when physical activity is not required. The problem is, food is nearly always available and physical activity is seldom required (Bellisari 2008; Peters et al. 2002).

Although OOA and OOM children were more active than contemporary-living children regardless of the day, on weekdays both groups spent similar amounts of time being sedentary. There were however, clear differences in how sedentary time was accumulated with group differences evident on weekend days. This is an important finding as there is mounting literature linking overall sedentary time and its pattern of accrual to health risks (Hamilton et al. 2007; Healy et al. 2008b; Healy et al. 2008a; Pate et al. 2008; Tremblay et al. 2010). For example, on Sundays virtually all OOA and OOM children attend church. However, unlike the active commute to school, children travel to church with their families via horse and buggy and then sit through a service lasting two or more hours. These religious observances are easily discernable as sedentary bouts in Figure 4.3 when the activity profile on Saturday is compared to Sunday. No such clearly demarcated bout of sedentary time was found for the contemporary groups on Sunday. The notion that religious observance can have an impact on the accrual of physical activity and sedentary time has been studied before. Kahan (2004) found that in a group of Jewish adolescents, those most likely to observe the Sabbath and attend a synagogue accrued less MVPA and less sedentary time compared to the less observant. Another contributing factor to the relatively large amounts of sedentary time during the school day relates to the fact that OOA and OOM children are educated in one-room school houses with limited space for moving around both during and between lessons. In contrast, contemporary children attend relatively large schools and often change classrooms between lessons and may have physical education classes scheduled throughout the school day. Cohen and colleagues (2008) recently showed that the indoor square footage of a school can contribute 4 and 16% to the light and MVPA of adolescent girls respectively.

A strength of this study was the use of objective measurements of physical activity (Shephard 2003). Another strength is the detailed analysis of the accelerometry data in terms of intensity and temporality. However, there are limitations to accelerometry, most notably, their inability to assess lifting and carrying activities, cycling, water-based activities, and the general lack of contextual information relating to activity mode and/or location/domain (Montoye et al. 1996). For example, the fact that waist mounted accelerometers do not measure cycling could have limited the true quantification of MVPA in the OOM, RSK, and USK children all of whom ride bicycles; whereas the OOA children are disallowed. This explanation may partly explain the relatively high amounts of MVPA in the OOA children compared to the OOM children;

however, one cannot forget the fact that OOM farms and homesteads are allowed some labour mechanization (e.g., tractors). Unfortunately no information was collected on activity mode. Although attempts were made to control for the month of data collection, seasonal differences were not specifically measured. In addition, specific information was not collected regarding school start and end times, recess, or lunch. Another limitation was that selection bias could not be ruled out due to the non-random nature of the sample. Although virtually all OOA children were measured, less than half of the OOM children were sampled; however, it is unlikely that the OOM children are at risk of physical activity related non-response bias as it was the most technologically conservative families that declined to participate. In contrast, the self-identifying process of contemporary school selection likely resulted in schools participating that were very supportive of physical activity. We are confident that, if anything, these limitations work to disprove our hypotheses and therefore strengthen our findings. Finally, it should be noted that this study included only children in technologically conservative Amish and Mennonite communities. Therefore, these results should not be generalized to other less conservative religiocultural communities where fewer families farm, and modern technology is more prevalent, as physical activity is likely to be lower in these groups.

4.5 Conclusion

Though cross-sectional, these data suggest that contemporary/modern living is associated with lower levels of moderate and vigorous intensity physical activity compared to lifestyles representative of earlier generations. Analyzing the physical activity and sedentary patterns of traditional lifestyle groups such as the OOA and OOM can provide valuable insight into the quantity and quality of physical activity necessary to promote health. Future work in this area should address differences in how children fractionalize (i.e., accumulate in bouts) their physical activity and sedentary time and the impact these behaviours have on health.

4.6 Acknowledgements

The authors express their appreciation to all the children who participated in this study and to David Luthy for his assistance and guidance with the Amish community and Levi Frey for his assistance with the Mennonite community. This research was supported by the Canadian Population Health Initiative of the Canadian Institute for Health Information and the Charlie and Mai Coffey endowment in Exercise Science at the University of Tennessee.

Chapter 5: General Discussion

What determines which tool is the best for measuring physical activity? The simple answer is function. Chicago architect Louis Sullivan (1856-1924), father of the skyscraper, observed that "form follows function". This is as true for the myriad of physical activity measurement tools that have evolved as it is for the structural elements of a building. However, it is function, not form, which is the critical evolutionary determinant. Therefore, it is important to understand that when little was known about physical activity and health, simple, unsophisticated and inexpensive methods (e.g., questionnaires) were used to demonstrate disease associations (Rennie and Wareham 1998). However, over the last few decades research has evolved from the description of simple relationships to more advanced applications such as: which aspects of physical activity are of importance? What quantity and quality of physical activity is necessary to stay healthy? Does timing matter; does physical activity in different life stages have different impact on disease? Over time, research has focused on related issues as well, such as: which factors affect the habits of health-enhancing physical activity? To answer these questions (Lagerros 2009) we need more accurate exposure quantification. As a result, the tools developed during the era of the 'descriptive phase' do not always meet the demands of the more advanced phase. Therefore, new improved, validated and reliable methods (such as accelerometers) are required and fortunately, this need is being met.

Today, accelerometers have become one of the most commonly used tools for measuring physical activity. The published literature is a testament to this fact. Searching the SciVerse Scopus abstract and citation database (www.scopus.com accessed 27/09/2010) using a simple search for "accelerometer or accelerometry or accelerometric" and "physical activity" in article title, abstract, or keywords yields 2193 articles to date (see Figure 5.1). Sifting through the data highlights the fact that the uptake of this technology was slow at first, with less than one article a year published from 1978-1987. However, by 1990 there was a steady increase in the use of accelerometers with 2003 marking an exponential rise in their use. In 2009 and 2010, on average, more than one 'accelerometer and physical activity' paper is published every day. However, the wide-scale acceptance of accelerometers as a viable tool for the measurement of physical activity and sedentary behaviour has come with some challenges. Because of their apparent simplicity, accelerometers are being used with little effort to understand the technology and its inherent limitations. This can result in the outright misuse of the "black box" by some researchers or results in a failure to exploit the devices full potential.

Therefore the overall purpose of this three study dissertation was to determine the impact accelerometer model has on the development of a comprehensive physical activity and sedentary behaviour profile and to design and apply novel profiling methods in an order to gain new insights into children's physical activity. The purpose of **Study One** was to determine which of the three most commonly used accelerometer models has the best intra- and inter-instrument reliability using a mechanical laboratory setup. This study also determined the effect acceleration and frequency have on these reliability measures. The purpose of **Study Two** was to highlight the detailed physical activity and sedentary information that can now be examined to understand the relationships between health and movement frequency, intensity, and duration more comprehensively. The purpose of **Study Three** was to profile the physical activity and sedentary behaviours of Old Order Amish (OOA), Old Order Mennonite (OOM), and contemporary-living children as a means of assessing the influence of lifestyle. Hypothesis 1 was that group differences in physical activity would be evident (i.e., Amish > Mennonite > contemporary-living children). Hypothesis 2 was that group differences in sedentariness would be evident (i.e., contemporary-living > Mennonite > Amish children). Hypothesis 3 was that the timing (e.g., time of day and day of the week) of the physical activity of the Amish and Mennonite children would differ from that of the contemporary-living children.

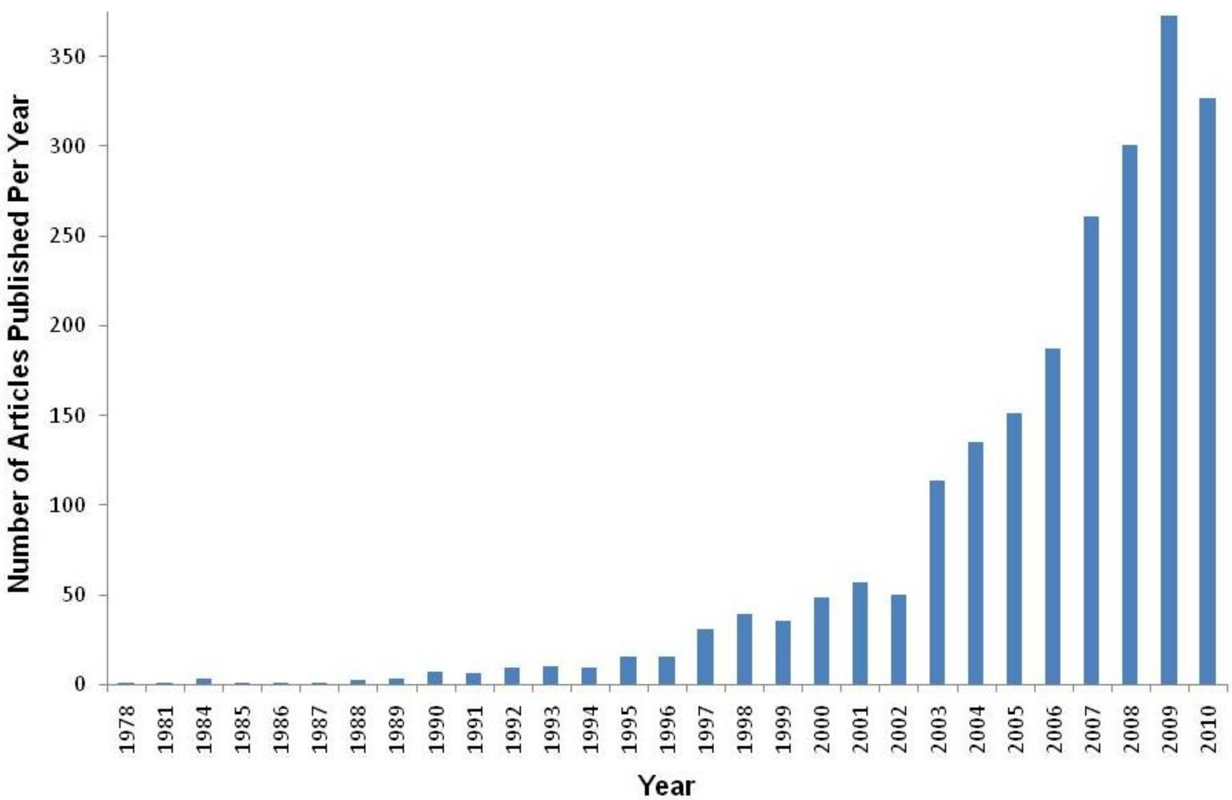


Figure 5.1. Histogram illustrating the year-on-year rise in the use of accelerometers in physical activity research
Notes: i) 2010 is a partial year; ii) this figure is modelled off Troiano (2005)

5.1 Summary of Main Findings

In **Study One**, Experiment 1 highlighted the poor reliability of the RT3 accelerometer (intra- and inter-instrument CV > 40%). Experiments 2 and 3 clearly indicated that the Actical (CV_{intra} = 0.5%, CV_{inter} = 5.4%) was more reliable than the Actigraph (CV_{intra} = 3.2%, CV_{inter} = 8.6%). Variability in the Actical was negatively related to the acceleration of the condition, whereas no relationship was found between acceleration and reliability in the Actigraph.

Variability in the Actigraph was negatively related to the frequency of the condition, whereas no relationship was found between frequency and reliability in the Actical. Of the three accelerometer models measured in this study, the Actical had the best intra- and inter-instrument reliability. However, discrepant trends in the variability of Actical and Actigraph counts across accelerations and frequencies preclude the selection of a superior model. These findings suggest that accelerometer users need to ensure they understand the device specifications of their measurement technologies or more importantly, understand the implications of using a particular device.

In the process of performing the literature review and generating the activity and sedentary profiles for **Study Two** it became clear just how information-rich accelerometry data are. It also became clear that careful attention must be paid to the comprehensive operational definition of the outcome variables in order to ensure potential users have a full appreciation for and understanding of the data. Objective physical activity monitors are being used more frequently to address this demand. These devices allow for a much more detailed profiling of physical activity and sedentariness if the data collected are used to their full potential. However, care must be taken to ensure that findings are interpreted correctly, as there is opportunity for misleading and/or opportunistic data reporting. Physical activity and/or sedentary profiles have the potential to rapidly increase our understanding of these complex, multi-dimensional behaviours. This "next generation" of physical activity and sedentary indices creates enormous research potential; ultimately, this can further inform the development, customization and modification of physical activity guidelines for Canadians. In fact, as this thesis goes to print, the Canadian Society for Exercise Physiology has just released its updated family of Physical Activity Guidelines (Tremblay et al. 2011b). In addition to the revision of the existing physical activity guidelines, CSEP has also minted the world's first Sedentary Behaviour Guidelines (Tremblay et al. 2011a). Growing public health concerns about inadequate physical activity and excessive sedentary time are creating demands for improved population health promotion and surveillance of these behaviours.

In **Study Three** group differences in moderate physical activity were found on weekdays between all lifestyle groups (Old Order Amish > Old Order Mennonite > Urban Saskatchewan > Rural Saskatchewan). On the weekend, the group differences in moderate physical activity persisted between, but not within, lifestyle groups (OOA = OOM > USK = RSK). During school hours, all groups had similar activity and sedentary timings; however, they differed in magnitude, with the OOA and OOM being both more sedentary and more active. In comparison with the children in school, the OOA and the OOM children had 44% lower sedentary time out of school compared with only 15% lower for RSK and USK children. Although cross sectional, these data suggest that contemporary/modern living is associated with lower levels of moderate- and vigorous-intensity physical activity compared with lifestyles representative of earlier generations. Analyzing the physical activity and sedentary patterns of traditional lifestyle groups such as the OOA and the OOM can provide valuable insight into the quantity and quality of physical activity necessary to promote health.

5.2 The Goal of Physical Activity Measurement

The primary goal of physical activity measurement is to obtain the best possible scientific evidence to enhance our understanding of the role of individual and contextual level factors in influencing physical activity and sedentary behaviours (Bauman et al. 2006b). This information is crucial in order to develop and implement effective physical activity and population health promotion programs. Simple epidemiological measures of physical activity, such as questionnaires, have proved adequate to demonstrate associations with a number of chronic disease outcomes; however, they rarely separate physical activity into its different dimensions, nor have they facilitated an estimation of dose-response effects (Wareham and Rennie 1998). For example, because of the use of simple questionnaires in studies of the aetiology of type 2 diabetes, it is unclear whether public health interventions should focus on increasing total energy expenditure or rather to increase physical activity (Wareham and Rennie 1998). These are distinctly different public health targets, as it requires vastly different public health messaging (Brawley and Latimer 2007) to advocate vigorous activity rather than simply increasing energy turnover. Therefore, the appropriate design of interventions hinges on the availability of precise epidemiological data, which is, in turn, dependent upon having valid physical activity measures. Improved measures would be of use in aetiological studies, in tracking trends in physical activity within populations, making objective comparisons between populations and in monitoring the effect of interventions (Wareham and Rennie 1998).

5.3 Physical Activity Profiling

The epidemic rise in the prevalence of obesity and type 2 diabetes, among 33 other chronic diseases, is a consequence of the worldwide trend of engineering physical activity out of our daily lives. The World Health Organization (2009) has concluded that 3.2 million premature deaths each year are a result of sedentariness. In fact, physical activity has joined diet and tobacco use as one of the leading modifiable risk factors for chronic disease. As a result, a considerable amount of epidemiological research has been conducted to determine the nature of the relationship between physical activity and health.

Fortunately, physical activity and sedentary profiling generates an impressive suite of outcome variables that once scrutinized thoroughly, contribute to our understanding of these complex behaviours. Although the relationship between children's physical activity and health has been tenuous in the past (Riddoch 1995), stronger associations are increasingly being found in studies that employ objective measurement techniques (Andersen 2006; Dencker 2008; Hopkins 2009; LeBlanc 2010; Mark 2008; Mark 2009; Riddoch 2009; Schmidt 2008; Steele 2009). For example, Andersen et al. (2006) published convincing data from the European Youth Heart Study, on over 2000 British children, showing an inverse graded association between accelerometer-measured physical activity and fatness (among other cardiometabolic risk factors). These cross sectional data were reaffirmed by the results from the Avon Longitudinal Study of Parents and Children which also showed strong relationships between accelerometer-measured physical activity and obesity (Ness et al. 2007; Riddoch et al. 2009). These already convincing data were further supported by data from NHANES that showed an inverse dose–response relationship between the blood pressure of children and youth and both total activity and MVPA (Mark et al. 2008). A year later, Mark et al. (2009) confirmed a similar relationship between more continuous bouts of MVPA and body mass index. Although these findings provide important new insights into the physical activity and sedentary behaviours of children, to date the outcome variables studied in relation to physical activity and sedentariness have been limited. We do not know the full range of predictors of physical activity, nor do we have sufficient knowledge of how different levels, patterns, and timings of activity and sedentariness are associated with physiological and psychological health outcomes. As a result, we still have inadequate evidence to inform the design of physical activity interventions that will be effective in improving children's health.

5.4 The Importance of Understanding the Black Box

As advances are made in the use of accelerometers in surveillance and intervention research, it becomes increasingly important to understand how much variability exists between models, between units, and how variable are data over time (Welk et al. 2004). Researchers have used various mechanical apparatuses to oscillate accelerometers in various axes in an effort to assess reliability. Examples include turntables (Metcalf et al. 2002), rotating wheel setups Moeller et al. 2008), vibration tables (Powell et al. 2003), and various types of mechanical shakers (Esliger and Tremblay 2006; Kransoff et al. 2008; Rothney et al. 2008; Van Hees et al. 2009). These apparatuses allow the researcher to control the magnitude of the acceleration being imparted as well as the frequency of the oscillation, two key variables that contribute to the accelerometer's output. Mechanical setups, by virtue of the precise control of the experimental conditions, are able to determine the variability attributed solely to the accelerometer.

As with any method of measurement, it is important to identify and quantify the different sources of variation so actions can be taken to try and reduce or control them. For example, device failures and/or batch effects (i.e., serial number clusters of high or low output units) can easily be identified using mechanical testing regimens (Esliger and Tremblay 2006). This type of testing is important because if the measurement error intrinsic to the accelerometer is found to be small, then focus can shift to other sources of variation (e.g., position worn on the body, variation over time (e.g., day-to-day, week-to-week, season-to-season) (Metcalf et al. 2002). Moreover, quantifying the inherent variation in accelerometer models allows for better interpretation of results and helps inform accelerometer purchasing decisions. In addition, data from precisely controlled mechanical experiments may help researchers determine within and between accelerometer model equivalency. This will become increasingly important as research groups begin to share and/or pool large amounts of accelerometer data (e.g., the International Children's Accelerometry Database (ICAD) aims to pool Actigraph data on >25,000 children from 20 studies from 11 different countries) or large surveys such as NHANES are obliged to change/update the type of monitor used. Researchers employing accelerometers to assess physical activity should treat their accelerometers with the same care as those working with laboratory-based clinical chemistry to achieve high quality data (Welk 2005). Because reliability sets the limit on validity, proper checks should be undertaken on all devices prior to each and every use.

While developed primarily for assessing movement, there has been considerable interest in using accelerometers to also indicate levels of sedentary behaviour (Healy, et al., 2008; Matthews, et al., 2008; Pate, O'Neill, & Lobelo, 2008; Reilly, et al., 2008; Sardinha, et al., 2008; Williams, et al., 2008). However, this new functionality has only recently been considered in the design stage of device development. As a result, current generation accelerometers such as the Actical and Actigraph, have not undergone rigorous reliability and validity testing to ensure these new outcomes can be accurately quantified. For example, a study by Silva et al. (2010) recently showed that testing at the 0.05g threshold detection level of the Actigraph GT1M only resulted in 10 of the 50 units registering any movement. These mechanically derived results are consistent with a previous study that reported increases in zero count values observed with GT1M data (Rothney, et al., 2008). Variability in threshold detection between units could have a significant impact on the number of sedentary epochs detected for a given study participant. This is particularly worrying considering how reliant the field has become on accelerometer data reduction procedures that scan and exclude continuous zero strings above a given threshold in an effort to determine accelerometer wear vs. non-wear. Further lab-based and field-based studies are warranted to clarify the impact of wide ranging threshold detection levels in the Actigraph GT1M accelerometer and indeed other common accelerometric devices.

5.5 Limitations of Accelerometers

There are numerous limitations of using accelerometry to assess habitual physical activity. Accelerometers are usually expensive, may be obtrusive, cannot be worn in certain environments (e.g., contact sports, underwater – although some newer models are waterproof), create the potential for subject reactivity, are susceptible to data loss because of instrument failure or tampering, and at present require significant data cleaning, reduction and translation for most research or physical activity counselling purposes. In addition, the utility of accelerometers is affected by the participant's commitment to wear the device and follow the deployment instructions. Research suggests that 4-7 days of monitoring are required to obtain a reliable assessment of physical activity behaviour (Janz et al. 1995; Trost et al. 2000) because between-day stability is increased with the number of days assessed. Furthermore, because the accuracy of measurement is based on proper physical orientation (aligned with appropriate axis), the quality of the data may be compromised if misplaced because of body size or shape, clothing peculiarities or improper instruction.

In addition to cost, measurement logistics and data management issues, there are both theoretical and technical limitations of accelerometry. When a person moves, the limbs and/or body are accelerated, theoretically in proportion to the muscular force exerted, and thus to energy expenditure. Portable accelerometers measure accelerations of the body part to which they are attached, producing data in the form of counts per minute or estimated energy expenditure.

Although the accelerometer provides an objective summary of body movements, it often underestimates energy expenditure because it cannot detect physical activity in free living situations where much of the body remains stationary, for example, during cycling, resistance training or seated assembly line work (Montoye et al. 1996; Meijer et al, 1989; Sallis et al. 1990). Uniaxial accelerometers have the obvious limitation of detecting movement in only one plane. Newer triaxial and/or omnidirectional devices may help to overcome this limitation. Regardless, accelerometers are unable to detect additional energy expenditure resulting from lifting or carrying additional weight, climatic or thermal challenges or variations in footing or footwear (Montoye et al. 1996). Highlighting the limitations of accelerometry for assessing physical activity further, it has been suggested that accelerometers are able to estimate energy expenditure more accurately at low levels of activity, whereas heart rate monitors are more valid for energy expenditures at high levels of energy output (Luke et al. 1997).

Although some preliminary work has been done to adjust movement count interpretation across age during childhood the work has been anchored to chronological age (Puyau et al. 2002; Trost et al. 2002). More work is required to understand the effects of changes in growth and maturation particularly for longitudinal or long-term follow-up studies. Where multiple measurement periods are employed, efforts should be made to match participants with accelerometers to minimize the impact of inter-instrument variability (Metcalf et al. 2002). Despite the limitations of accelerometery, accelerometers have become the most common tool used to measure physical activity and sedentariness (Welk 2002).

Chapter 6: Future Research and Conclusions

6.1. Future Research

Accelerometry data for the purpose of physical activity monitoring has been tremendously under-utilized. By taking better advantage of the richness of the data collected, new opportunities for research are opened. Following are areas where future research is required:

1. Additional analyses of accelerometer data are required to better assess physical activity profiles (time of day activity distributions, weekly variations) and how these vary across age, sex, and ethnicity.
2. Additional work to describe seasonal (monthly) variation in activity and activity patterns is required.
3. Work to clarify how longitudinal data should be modeled to adjust for changes resulting from growth and development, aging, or changes in body weight is required.
4. Further investigation of the influence of varying the epoch duration on outcome variables, including meeting physical activity guidelines, is required.
5. Pending some acceptance of standardized procedures for reporting accelerometer data, inter-study comparisons should be made to examine variations in physical activity and sedentary behaviours.

Research exploring how current accelerometry technology can be modified or advanced to better accommodate physical activity data collection is desperately required. In many situations it may be advisable to adopt multiple simultaneous approaches, such as accelerometry (to provide an assessment of frequency, intensity, and duration) and self-report (to provide activity mode or type, and context), as additional information gathered would lead to a more complete profile of physical activity. In addition, the combination of methods with uncorrelated error would result in an improved estimation of the true exposure and is an important area for research.

6.2 Conclusions

Growing public health concerns about inadequate physical activity and excessive sedentariness are creating demands for improved surveillance of these important behaviours. Physical activity is a complex and multidimensional human behaviour (LaPorte et al. 1985). Measuring the quantity and quality of physical activity requires the use of valid and reliable methods (Caspersen et al., 1998). Objective physical activity monitors are being used more frequently to address this demand and accelerometers are at the forefront of these tools. These devices allow for a much more detailed profiling of physical activity and sedentary behaviour if the data collected are analyzed and used to their full potential. However, care must be taken to ensure that findings are interpreted correctly, as there is opportunity for misleading and/or opportunistic data reporting (Olds et al. 2007). This "next generation" of physical activity and sedentary indices creates enormous research potential; ultimately, this can further inform our understanding of the complex relationship between physical activity and health.

The purpose of this dissertation was to develop research findings to assist the development of 'Best Practices' as it relates to the objective measurement of physical activity. The three areas of focus were: 1) determining which accelerometer to use for a given application, 2) accelerometric data reduction and the generation of outcome variables, and 3) profiling/interpreting physical activity and sedentary data. These issues, as identified by a recent 'Best Practices' conference (described in greater detail on page 3 of this dissertation), are seen as the major hurdles in the evolution of the accelerometric measurement of physical activity.

Study One explored the comparative reliability of three commonly used accelerometers and in so doing, highlighted the considerable differences in accelerometer output that can occur as a result of the technical specifications of a given accelerometer model. The results of Study One will be useful for researchers and practitioners to inform their decisions as to what accelerometer technology they should deploy for their given research application. In addition, the robust technical reliability methods developed in Study One are replicable and adaptable to suit the needs of a growing cadre of physical activity measurement specialists. Study Two summarized the various accelerometer data reduction strategies and methods used for outcome variable extraction. Study Two went on to explore the physical activity and sedentary behaviour profiling possibilities that current generation accelerometers have the potential to provide. The final study of the dissertation, Study Three, employed a descriptive study design that aimed to profile the physical activity and sedentary behaviours of groups of children known to differ in these important lifestyle behaviours. This study was designed to be a 'test case' to determine if the methods developed in Study Two would be useful for comparing and contrasting movement related lifestyle behaviours. The richness of the behavioural profiling data that emanated from Study Three is a testament to the utility to this data mining approach. Collectively, these three dissertation studies complement one another and refine our understanding of these robust measurement tools and in so doing, evolve the 'Best Practices' of accelerometry.

References

1. Acheson KJ, Campbell IT, Edholm OG, Miller DS, Stock MJ. The measurement of daily energy expenditure--an evaluation of some techniques. *Am J Clin Nutr.* 1980;33(5):1155-64.

2. Adamo KB, Prince SA, Tricco AC, Connor-Gorber S, Tremblay M. A comparison of indirect versus direct measures for assessing physical activity in the pediatric population: a systematic review. *Int J Pediatr Obes.* 2009;4(1):2-27.

3. Adams SA, Matthews CE, Ebbeling CB, Moore CG, Cunningham JE, Fulton J, Hebert JR. The effect of social desirability and social approval on self-reports of physical activity. *Am J Epidemiol.* 2005;161(4):389-98.

4. Ainsworth BE, Haskell WL, Leon AS, Jacobs DR, Jr., Montoye HJ, Sallis JF, Paffenbarger RS, Jr. Compendium of physical activities: classification of energy costs of human physical activities. *Med Sci Sports Exerc.* 1993a;25(1):71-80.

5. Ainsworth BE, Haskell WL, Whitt MC, Irwin ML, Swartz AM, Strath SJ, O'Brien WL, Bassett DR, Jr., Schmitz KH, Emplaincourt PO, Jacobs DR, Jr., Leon AS. Compendium of physical activities: an update of activity codes and MET intensities. *Med Sci Sports Exerc.* 2000;32(9 Suppl):S498-S504.

6. Ainsworth BE, Leon AS, Richardson MT, Jacobs DR, Paffenbarger RS, Jr. Accuracy of the College Alumnus Physical Activity Questionnaire. *J Clin Epidemiol.* 1993b;46(12):1403-11.

7. Andersen LB, Harro M, Sardinha LB, Froberg K, Ekelund U, Brage S, Anderssen SA. Physical activity and clustered cardiovascular risk in children: a cross-sectional study (The European Youth Heart Study). *Lancet.* 2006;368(9532):299-304.

8. Andersen LB, Wedderkopp N, Hansen HS, Cooper AR, Froberg K. Biological cardiovascular risk factors cluster in Danish children and adolescents: the European Youth Heart Study. *Prev Med.* 2003;37(4):363-7.

9. Armstrong N. Young people's physical activity patterns as assessed by heart rate monitoring. *J Sports Sci.* 1998;16:S9-S16.

10. Armstrong N and Bray S. Physical activity patterns defined by continuous heart rate monitoring. *Arch Dis Child.* 1991;66(2):245-7.

11. Atwater WO and Benedict FG. Experiments on th emetabolism of matter and energy in the human body, 1900-1902. Bull. no. 136. 1903. Washington D.C., United States Department of Agriculture Office of Experiment Stations, United States Government Printing Office.

12. Bailey DA, McKay HA, Mirwald RL, Crocker PR, Faulkner RA. A six-year longitudinal study of the relationship of physical activity to bone mineral accrual in growing children: the university of Saskatchewan bone mineral accrual study. *J Bone Miner Res.* 1999;14(10):1672-9.

13. Bailey RC, Olson J, Pepper SL, Porszasz J, Barstow TJ, Cooper DM. The level and tempo of children's physical activities: an observational study. *Med Sci Sports Exerc.* 1995;27(7):1033-41.

14. Bassett DR. Physical activity of Canadian and American children: a focus on youth in Amish, Mennonite, and modern cultures. *Appl Physiol Nutr Metab.* 2008;33(4):831-5.

15. Bassett DR, Jr. Validity and reliability issues in objective monitoring of physical activity. *Res Q Exerc Sport.* 2000;71(2 Suppl):S30-S36.

16. Bassett DR, Jr., Ainsworth BE, Leggett SR, Mathien CA, Main JA, Hunter DC, Duncan GE. Accuracy of five electronic pedometers for measuring distance walked. *Med Sci Sports Exerc.* 1996;28(8):1071-7.

17. Bassett DR, Jr., Cureton AL, Ainsworth BE. Measurement of daily walking distance-questionnaire versus pedometer. *Med Sci Sports Exerc.* 2000;32(5):1018-23.

18. Bassett DR, Jr. & Strath SJ Use of Pedometers to Assess Physical Activity. In: Welk Geditor *Physical Activity Assessments for Health-Related Research.* Champaign: Human Kinetics; 2002. p. 163-75.

19. Bassett DR, Jr., Tremblay MS, Esliger DW, Copeland JL, Barnes JD, Huntington GE. Physical activity and body mass index of children in an old order Amish community. *Med Sci Sports Exerc.* 2007;39(3):410-5.

20. Bellisari A. Evolutionary origins of obesity. *Obes Rev.* 2008;9(2):165-80.

21. Berman N, Bailey R, Barstow TJ, Cooper DM. Spectral and bout detection analysis of physical activity patterns in healthy, prepubertal boys and girls. *American Journal of Human Biology.* 1998;10:289-97.

22. Black AE, Prentice AM, Coward WA. Use of food quotients to predict respiratory quotients for the doubly-labelled water method of measuring energy expenditure. *Hum Nutr Clin Nutr.* 1986;40(5):381-91.

23. Booth FW, Chakravarthy MV, Gordon SE, Spangenburg EE. Waging war on physical inactivity: using modern molecular ammunition against an ancient enemy. *J Appl Physiol.* 2002;93(1):3-30.

24. Bradfield RB, Huntzicker PB, Fruehan GJ, III. Errors of group regressions for prediction of individual energy expenditure. *Am J Clin Nutr.* 1970;23(8):1015-6.

25. Brage S, Brage N, Wedderkopp N, Froberg K. Reliability and validity of the Computer Science and Applications accelerometer in a mechanical setting. *Measurement in Physical Education and Exercise Science.* 2003;7(2):101-19.

26. Brawley LR and Latimer AE. Physical activity guides for Canadians: messaging strategies, realistic expectations for change, and evaluation. *Can J Public Health.* 2007;98 Suppl 2:S170-S184.

27. Cameron C, Wolfe R, Craig CL. Physical activity and sport: encouraging children to be active. 2007. Ottawa, ON, Canadian Fitness and Lifestyle Research Institute.

28. Canadian Pediatric Society Psychosocial Pediatrics Committee. Impact of media use on children and youth. *Paediatr Child Health.* 2003;8(5):301-17.

29. Caspersen CJ. Physical activity epidemiology: concepts, methods, and applications to exercise science. *Exerc Sport Sci Rev.* 1989;17:423-73.:423-73.

30. Caspersen CJ, Nixon PA, DuRant RH. Physical activity epidemiology applied to children and adolescents. *Exerc Sport Sci Rev.* 1998;26:341-403.:341-403.

31. Cavagna GA and Margaria R. Mechanics of walking. *J Appl Physiol.* 1966;21(1):271-8.

32. Chakravarthy MV and Booth FW. Eating, exercise, and "thrifty" genotypes: connecting the dots toward an evolutionary understanding of modern chronic diseases. *J Appl Physiol.* 2004;96(1):3-10.

33. Chen KY and Bassett DR, Jr. The technology of accelerometry-based activity monitors: current and future. *Med Sci Sports Exerc.* 2005;37(11 Suppl):S490-S500.

34. Chu EY, McManus AM, Yu CC. Calibration of the RT3 accelerometer for ambulation and nonambulation in children. *Med Sci Sports Exerc.* 2007;39(11):2085-91.

35. Church TS, Earnest CP, Skinner JS, Blair SN. Effects of different doses of physical activity on cardiorespiratory fitness among sedentary, overweight or obese postmenopausal women with elevated blood pressure: a randomized controlled trial. *JAMA.* 2007;297(19):2081-91.

36. Cohen D, Scott M, Wang FZ, McKenzie TL, Porter D. School design and physical activity among middle school girls. *J Phys Act Health.* 2008;5(5):719-31.

37. Craig R, Mindell J, Hirani V. Health Survey for England 2008: Physical activity and fitness. Vol 1. 2009. London, UK, Joint Health Surveys Unit, National Centre for Social Research.

38. Crouter SE, Schneider PL, Karabulut M, Bassett DR, Jr. Validity of 10 electronic pedometers for measuring steps, distance, and energy cost. *Med Sci Sports Exerc.* 2003;35(8):1455-60.

39. Daar AS, Singer PA, Persad DL, Pramming SK, Matthews DR, Beaglehole R, Bernstein A, Borysiewicz LK, Colagiuri S, Ganguly N, Glass RI, Finegood DT, Koplan J, Nabel EG, Sarna G, Sarrafzadegan N, Smith R, Yach D, Bell J. Grand challenges in chronic non-communicable diseases. *Nature.* 2007;450(7169):494-6.

40. Davidson L, McNeill G, Haggarty P, Smith JS, Franklin MF. Free-living energy expenditure of adult men assessed by continuous heart-rate monitoring and doubly-labelled water. *Br J Nutr.* 1997;78(5):695-708.

41. Dishman RK, Washburn RA, Schoeller DA. Measurement of physical activity. *Quest.* 2001;53:295-309.

42. Dollman J, Okely AD, Hardy L, Timperio A, Salmon J, Hills AP. A hitchhiker's guide to assessing young people's physical activity: Deciding what method to use. *J Sci Med Sport.* 2008a.

43. Dollman J, Okely AD, Hardy L, Timperio A, Salmon J, Hills AP. A hitchhiker's guide to assessing young people's physical activity: Deciding what method to use. *J Sci Med Sport.* 2008b.

44. Eisenmann JC, Katzmarzyk PT, Tremblay MS. Leisure-time physical activity levels among Canadian adolescents, 1981-1998. *J Phys Act Health.* 2004;1:154-62.

45. Ekelund U, Brage S, Froberg K, Harro M, Anderssen SA, Sardinha LB, Riddoch C, Andersen LB. TV viewing and physical activity are independently associated with metabolic risk in children: the European Youth Heart Study. *PLoS Med.* 2006;3(12):e488.

46. Elia M, Fuller N, Murgatroyd P. The potential use of the labelled bicarbonate method for estimating energy expenditure in man. *Proc Nutr Soc.* 1988;47(3):247-58.

47. Epstein LH, Paluch RA, Coleman KJ, Vito D, Anderson K. Determinants of physical activity in obese children assessed by accelerometer and self-report. *Med Sci Sports Exerc.* 1996;28(9):1157-64.

48. Esliger DW, Copeland JL, Barnes JD, Tremblay MS. Standardizing and optimizing the use accelerometer data for free-living physical activity monitoring. *J Phys Act Health.* 2005;2(3):366-83.

49. Esliger DW and Tremblay MS. Physical activity and inactivity profiling: the next generation. *Can J Public Health.* 2007;98 Suppl 2:S195-S207.

50. Evenson KR, Catellier DJ, Gill K, Ondrak KS, McMurray RG. Calibration of two objective measures of physical activity for children. *J Sports Sci.* 2008;1-9.

51. Fairweather SC, Reilly JJ, Grant S, Whittaker A, Paton JY. Using the Computer Science and Applications (CSA) activity monitor in preschool children. *Pediatric Exercise Science.* 1999;11:413-20.

52. Feinstein AR. Clinical biostatistics. XII. On exorcising the ghost of Gauss and the curse of Kelvin. *Clin Pharmacol Ther.* 1971;12(6):1003-16.

53. Ferris TLJ. A new definition of measurement. *Measurement.* 2004;36(1):101-9.

54. Freedson PS, Melanson E, Sirard J. Calibration of the Computer Science and Applications, Inc. accelerometer. *Med Sci Sports Exerc.* 1998;30(5):777-81.

55. Freedson PS and Miller K. Objective monitoring of physical activity using motion sensors and heart rate. *Res Q Exerc Sport.* 2000;71(2 Suppl):S21-S29.

56. Gibney ER, Murgatroyd P, Wright A, Jebb S, Elia M. Measurement of total energy expenditure in grossly obese women: comparison of the bicarbonate-urea method with whole-body calorimetry and free-living doubly labelled water. *Int J Obes Relat Metab Disord.* 2003;27(6):641-7.

57. Godfrey A, Conway R, Meagher D, OLaighin G. Direct measurement of human movement by accelerometry. *Med Eng Phys.* 2008;30(10):1364-86.

58. Going SB, Levin S, Harrell J, Stewart D, Kushi L, Cornell CE, Hunsberger S, Corbin C, Sallis J. Physical activity assessment in American Indian schoolchildren in the Pathways study. *Am J Clin Nutr.* 1999;69(4 Suppl):788S-95S.

59. Goran MI, Nagy TR, Gower BA, Mazariegos M, Solomons N, Hood V, Johnson R. Influence of sex, seasonality, ethnicity, and geographic location on the components of total energy expenditure in young children: implications for energy requirements. *Am J Clin Nutr.* 1998;68(3):675-82.

60. Gordon-Larsen P, Nelson MC, Popkin BM. Longitudinal physical activity and sedentary behavior trends: adolescence to adulthood. *Am J Prev Med.* 2004;27(4):277-83.

61. Hagstromer M, Troiano RP, Sjostrom M, Berrigan D. Levels and patterns of objectively assessed physical activity--a comparison between Sweden and the United States. *Am J Epidemiol.* 2010;171(10):1055-64.

62. Hamilton MT, Hamilton DG, Zderic TW. Role of low energy expenditure and sitting in obesity, metabolic syndrome, type 2 diabetes, and cardiovascular disease. *Diabetes.* 2007;56(11):2655-67.

63. Hardman AE. Issues of fractionization of exercise (short vs long bouts). *Med Sci Sports Exerc.* 2001;33(6 Suppl):S421-S427.

64. Haskell WL. What to look for in assessing responsiveness to exercise in a health context. *Med Sci Sports Exerc.* 2001;33(6 Suppl):S454-S458.

65. Haskell WL. Physical activity, sport, and health: toward the next century. *Res Q Exerc Sport.* 1996;67(3 Suppl):S37-S47.

66. Health Canada and the Canadian Society for Exercise Physiology. Canada's physical activity guide for children. Cat.No.H39-611/2002-2E. 2002a. Ottawa, ON, Minister of Public Works and Government Services Canada.

67. Health Canada and the Canadian Society for Exercise Physiology. Handbook for Canada's physical activity guide to healthy active living. Cat. No. H39-429/1998-2E. 1998. Ottawa, ON, Health Canada.

68. Health Canada and the Canadian Society for Exercise Physiology. Canada's physical activity guide for youth. Cat.No.H39-611/2002-1E. 2002b. Ottawa, ON, Minister of Public Works and Government Services Canada.

69. Healy GN, Dunstan DW, Salmon J, Cerin E, Shaw JE, Zimmet PZ, Owen N. Objectively measured light-intensity physical activity is independently associated with 2-h plasma glucose. *Diabetes Care.* 2007;30(6):1384-9.

70. Healy GN, Dunstan DW, Salmon J, Cerin E, Shaw JE, Zimmet PZ, Owen N. Breaks in sedentary time: beneficial associations with metabolic risk. *Diabetes Care.* 2008a;31(4):661-6.

71. Healy GN, Wijndaele K, Dunstan DW, Shaw JE, Salmon J, Zimmet PZ, Owen N. Objectively measured sedentary time, physical activity, and metabolic risk: the Australian Diabetes, Obesity and Lifestyle Study (AusDiab). *Diabetes Care.* 2008b;31(2):369-71.

72. Hendelman D, Miller K, Baggett C, Debold E, Freedson P. Validity of accelerometry for the assessment of moderate intensity physical activity in the field. *Med Sci Sports Exerc.* 2000;32(9 Suppl):S442-S449.

73. Jacobs DR, Jr., Ainsworth BE, Hartman TJ, Leon AS. A simultaneous evaluation of 10 commonly used physical activity questionnaires. *Med Sci Sports Exerc.* 1993;25(1):81-91.

74. Jago R, Baranowski T, Baranowski JC, Cullen KW, Thompson DI. Social desirability is associated with some physical activity, psychosocial variables and sedentary behavior but

not self-reported physical activity among adolescent males. *Health Educ Res.* 2007a;22(3):438-49.

75. Jago R, Zakeri I, Baranowski T, Watson K. Decision boundaries and receiver operating characteristic curves: new methods for determining accelerometer cutpoints. *J Sports Sci.* 2007b;25(8):937-44.

76. Janz KF Use of Heart Rate Monitors to Assess Physical Activity. In: Welk Geditor *Physical Activity Assessments for Health-Related Research.* Champaign: Human Kinetics; 2002. p. 143-61.

77. Janz KF. Physical activity in epidemiology: moving from questionnaire to objective measurement. *Br J Sports Med.* 2006;40(3):191-2.

78. Janz KF, Burns TL, Levy SM, Torner JC, Willing MC, Beck TJ, Gilmore JM, Marshall TA. Everyday activity predicts bone geometry in children: the iowa bone development study. *Med Sci Sports Exerc.* 2004;36(7):1124-31.

79. Janz KF, Witt J, Mahoney LT. The stability of children's physical activity as measured by accelerometry and self-report. *Med Sci Sports Exerc.* 1995;27(9):1326-32.

80. Kahan D. Relationships among religiosity, physical activity, and sedentary behavior in Jewish adolescents. *Pediatr Exerc Sci.* 2004;16(1):54-63.

81. Katzmarzyk PT, Baur LA, Blair SN, Lambert EV, Oppert JM, Riddoch C. Expert panel report from the International Conference on Physical Activity and Obesity in Children, 24-27 June 2007, Toronto, Ontario: summary statement and recommendations. *Appl Physiol Nutr Metab.* 2008;33(2):371-88.

82. Katzmarzyk PT and Tremblay MS. Limitations of Canada's physical activity data: implications for monitoring trends. *Can J Public Health.* 2007;98 Suppl 2:S185-S194.

83. Kavanagh JJ and Menz HB. Accelerometry: a technique for quantifying movement patterns during walking. *Gait Posture.* 2008;28(1):1-15.

84. Kavanagh JJ, Morrison S, James DA, Barrett R. Reliability of segmental accelerations measured using a new wireless gait analysis system. *J Biomech.* 2006;39(15):2863-72.

85. Kesaniemi YK, Danforth E Jr, Jensen MD, Kopelman PG, Lefebvre P, Reeder BA. Dose-response issues concerning physical activity and health: an evidence-based symposium. *Med Sci Sports Exerc.* 2001;33(6 Suppl):S351-S358.

86. Kohl HW, Fulton JE, Caspersen CJ. Assessment of physical activity among children and adolescents: a review and synthesis. *Prev Med.* 2000;31(liv):S54-S76.

87. Kruger J, Ham SA, Kohl HW, III. Characteristics of a "weekend warrior": results from two national surveys. *Med Sci Sports Exerc.* 2007;39(5):796-800.

88. Kuhn TS. *The Structure of Scientific Revolutions.* 3 ed. Chicago: The University of Chicago Press; 1996.

89. Lagerros YT. Physical activity--the more we measure, the more we know how to measure. *Eur J Epidemiol.* 2009;24(3):119-22.

90. Lagerros YT and Lagiou P. Assessment of physical activity and energy expenditure in epidemiological research of chronic diseases. *Eur J Epidemiol.* 2007a;22(6):353-62.

91. Lagerros YT and Lagiou P. Assessment of physical activity and energy expenditure in epidemiological research of chronic diseases. *Eur J Epidemiol.* 2007b;22(6):353-62.

92. Lamonte MJ and Ainsworth BE. Quantifying energy expenditure and physical activity in the context of dose response. *Med Sci Sports Exerc.* 2001;33(6 Suppl):S370-S378.

93. Lanningham-Foster LM, Jensen TB, McCrady SK, Nysse LJ, Foster RC, Levine JA. Laboratory measurement of posture allocation and physical activity in children. *Med Sci Sports Exerc.* 2005;37(10):1800-5.

94. LaPorte RE, Montoye HJ, Caspersen CJ. Assessment of physical activity in epidemiologic research: problems and prospects. *Public Health Rep.* 1985;100(2):131-46.

95. Larose DT. *Discovering Knowledge in Data: An Introduction to Data Mining.* Hoboken, New Jersey: John Wiley & Sons; 2005. 4p.
Ref ID:

96. Laukkanen R and Virtanen PK. Heart rate monitors: State of the art. *J Sports Sci.* 1998;16:S3-S7.

97. Le Masurier GC, Lee SM, Tudor-Locke C. Motion sensor accuracy under controlled and free-living conditions. *Med Sci Sports Exerc.* 2004;36(5):905-10.

98. Le Masurier GC and Tudor-Locke C. Comparison of pedometer and accelerometer accuracy under controlled conditions. *Med Sci Sports Exerc.* 2003;35(5):867-71.

99. Lee IM. Dose-response relation between physical activity and fitness: even a little is good; more is better. *JAMA.* 2007;297(19):2137-9.

100. Lee IM and Paffenbarger RS, Jr. Physical activity and stroke incidence: the Harvard Alumni Health Study. *Stroke.* 1998;29(10):2049-54.

101. Lee IM, Sesso HD, Oguma Y, Paffenbarger RS, Jr. The "weekend warrior" and risk of mortality. *Am J Epidemiol.* 2004;160(7):636-41.

102. Levine JA, Eberhardt NL, Jensen MD. Role of nonexercise activity thermogenesis in resistance to fat gain in humans. *Science.* 1999;283(5399):212-4.

103. Levine JA, Lanningham-Foster LM, McCrady SK, Krizan AC, Olson LR, Kane PH, Jensen MD, Clark MM. Interindividual variation in posture allocation: possible role in human obesity. *Science.* 2005;307(5709):584-6.

104. Lifson N. Theory of use of the turnover rates of body water for measuring energy and material balance. *J Theor Biol.* 1966;12(1):46-74.

105. Livingstone MB. Heart-rate monitoring: the answer for assessing energy expenditure and physical activity in population studies? *Br J Nutr.* 1997;78:869-71.

106. Livingstone MB, Prentice AM, Coward WA, Ceesay SM, Strain JJ, McKenna PG, Nevin GB, Barker ME, Hickey RJ. Simultaneous measurement of free-living energy expenditure by the doubly labeled water method and heart-rate monitoring. *Am J Clin Nutr.* 1990;52(1):59-65.

107. Maas S, Kok ML, Westra HG, Kemper HC. The validity of the use of heart rate in estimating oxygen consumption in static and in combined static/dynamic exercise. *Ergonomics.* 1989;32(2):141-8.

108. Macera CA and Pratt M. Public health surveillance of physical activity. *Res Q Exerc Sport.* 2000;71(2 Suppl):S97-103.

109. Mahar MT & Rowe DA Construct Validity in Physical Activity Research. In: Welk Geditor *Physical Activity Assessments for Health-Related Research.* Champaign: Human Kinetics; 2002. p. 51-70.

110. Manson JE, Hu FB, Rich-Edwards JW, Colditz GA, Stampfer MJ, Willett WC, Speizer FE, Hennekens CH. A prospective study of walking as compared with vigorous exercise in the prevention of coronary heart disease in women. *N Engl J Med.* 1999;341(9):650-8.

111. Matthews CE, Chen KY, Freedson PS, Buchowski MS, Beech BM, Pate RR, Troiano RP. Amount of time spent in sedentary behaviors in the United States, 2003-2004. *Am J Epidemiol.* 2008;167(7):875-81.

112. Matthews CE, Jurj AL, Shu XO, Li HL, Yang G, Li Q, Gao YT, Zheng W. Influence of exercise, walking, cycling, and overall nonexercise physical activity on mortality in Chinese women. *Am J Epidemiol.* 2007;165(12):1343-50.

113. Mattocks C, Leary S, Ness A, Deere K, Saunders J, Kirkby J, Blair SN, Tilling K, Riddoch C. Intraindividual variation of objectively measured physical activity in children. *Med Sci Sports Exerc.* 2007;39(4):622-9.

114. McArdle WD, Katch FI, Katch VI Measurement of Human Energy Expenditure. In: *Exercise Physiology.* Baltimore: Lippincott Williams & Wilkins; 2001a. p. 174-86.

115. McArdle WD, Katch FI, Katch VI Energy Value of Food. In: *Exercise Physiology.* Baltimore: Lippincott Williams & Wilkins; 2001b. p. 108-14.

116. McKenzie TL Use of Direct Observation to Assess Physical Activity. In: Welk Geditor *Physical Activity Assessments for Health-Related Research.* Champaign: Human Kinetics; 2002. p. 176-96.

117. Melanson EL, Jr. and Freedson PS. Physical activity assessment: a review of methods. *Crit Rev Food Sci Nutr.* 1996;36(5):385-96.

118. Melanson EL, Knoll JR, Bell ML, Donahoo WT, Hill JO, Nysse LJ, Lanningham-Foster L, Peters JC, Levine JA. Commercially available pedometers: considerations for accurate step counting. *Prev Med.* 2004;39(2):361-8.

119. Metcalf BS, Curnow JS, Evans C, Voss LD, Wilkin TJ. Technical reliability of the CSA activity monitor: The EarlyBird Study. *Med Sci Sports Exerc.* 2002;34(9):1533-7.

120. Montoye HJ. Introduction: evaluation of some measurements of physical activity and energy expenditure. *Med Sci Sports Exerc.* 2000;32(9 Suppl):S439-S441.

121. Montoye HJ, Kemper HCG, Saris WHM, Washburn RA. *Measuring Physical Activity and Energy Expenditure.* Champaign, IL: Human Kinetics; 1996.

122. Montoye HJ and Taylor HL. Measurement of physical activity in population studies: a review. *Hum Biol.* 1984;56(2):195-216.

123. Nader PR, Bradley RH, Houts RM, McRitchie SL, O'Brien M. Moderate-to-vigorous physical activity from ages 9 to 15 years. *JAMA.* 2008;300(3):295-305.

124. Naisbitt J. *Megatrends.* 6th ed. New York: Warner Books; 1986.

125. National Center for Health Statistics. National Health and Nutrition Examination Survey Laboratory Protocol. http://www.cdc.gov/nchs/data/nhanes/nhanes_03_04/LAB.pdf . 2005.

126. National Institutes of Health. Grant: Improving diet and physical activity assessment. Available from http://grants.nih.gov/grants/guide/pa-files/PAR-06-104.html [accessed 18 May 2007] . 2002.

127. Ness AR, Leary SD, Mattocks C, Blair SN, Reilly JJ, Wells J, Ingle S, Tilling K, Smith GD, Riddoch C. Objectively measured physical activity and fat mass in a large cohort of children. *PLoS Med.* 2007;4(3):e97.

128. Olds T, Ridley K, Wake M, Hesketh K, Waters E, Patton G, Williams J. How should activity guidelines for young people be operationalised? *Int J Behav Nutr Phys Act.* 2007;4:43.

129. Pahkala K, Heinonen OJ, Lagstrom H, Hakala P, Hakanen M, Hernelahti M, Ruottinen S, Sillanmaki L, Ronnemaa T, Viikari J, Raitakari OT, Simell O. Clustered metabolic risk and leisure-time physical activity in adolescents: effect of dose? *Br J Sports Med.* 2010.

130. Parker SB, Hurley BF, Hanlon DP, Vaccaro P. Failure of target heart rate to accurately monitor intensity during aerobic dance. *Med Sci Sports Exerc.* 1989;21(2):230-4.

131. Pate RR, O'Neill JR, Lobelo F. The evolving definition of "sedentary". *Exerc Sport Sci Rev.* 2008;36(4):173-8.

132. Peters JC, Wyatt HR, Donahoo WT, Hill JO. From instinct to intellect: the challenge of maintaining healthy weight in the modern world. *Obes Rev.* 2002;3(2):69-74.

133. Pettee KK, Storti KL, Ainsworth BE, Kriska AM Measurement of physical activity and inactivity in epidemiologic studies. In: Lee IM, Blair SN, Manson JE, & Paffenbarger RS, Jr., editors. *Epidemiologic Methods in Physical Activity Studies.* New York: Oxford University Press; 2009. p. 15-33.

134. Pober DM, Staudenmayer J, Raphael C, Freedson PS. Development of novel techniques to classify physical activity mode using accelerometers. *Med Sci Sports Exerc.* 2006;38(9):1626-34.

135. Powell KE and Paffenbarger RS, Jr. Workshop on Epidemiologic and Public Health Aspects of Physical Activity and Exercise: a summary. *Public Health Rep.* 1985;100(2):118-26.

136. Powell SM, Jones DI, Rowlands AV. Technical variability of the RT3 accelerometer. *Med Sci Sports Exerc.* 2003;35(10):1773-8.

137. Puyau MR, Adolph AL, Vohra FA, Butte NF. Validation and calibration of physical activity monitors in children. *Obes Res.* 2002;10(3):150-7.

138. Puyau MR, Adolph AL, Vohra FA, Zakeri I, Butte NF. Prediction of activity energy expenditure using accelerometers in children. *Med Sci Sports Exerc.* 2004;36(9):1625-31.

139. Raj T, Kuriyan R, Kurpad AV. Bicarbonate kinetics in Indian males. *J Biosci.* 2006;31(2):273-80.

140. Ravussin E. Physiology. A NEAT way to control weight? *Science.* 2005;307(5709):530-1.

141. Reiser SJ. The medical influence of the stethoscope. *Sci Am.* 1979;240(2):148-6.

142. Rennie KL and Wareham NJ. The validation of physical activity instruments for measuring energy expenditure: problems and pitfalls. *Public Health Nutr.* 1998;1(4):265-71.

143. Richardson MT, Ainsworth BE, Jacobs DR, Leon AS. Validation of the Stanford 7-day recall to assess habitual physical activity. *Ann Epidemiol.* 2001;11(2):145-53.

144. Riddoch CJ, Mattocks C, Deere K, Saunders J, Kirkby J, Tilling K, Leary SD, Blair SN, Ness AR. Objective measurement of levels and patterns of physical activity. *Arch Dis Child.* 2007;92(11):963-9.

145. Ridley K, Ainsworth BE, Olds TS. Development of a compendium of energy expenditures for youth. *Int J Behav Nutr Phys Act.* 2008;5:45.

146. Ridley K and Olds TS. Assigning energy costs to activities in children: a review and synthesis. *Med Sci Sports Exerc.* 2008;40(8):1439-46.

147. Rowlands AV, Ingledew DK, Eston RG. The effect of type of physical activity measure on the relationship between body fatness and habitual physical activity in children: a meta-analysis. *Ann Hum Biol.* 2000;27(5):479-97.

148. Rowlands AV, Thomas PW, Eston RG, Topping R. Validation of the RT3 triaxial accelerometer for the assessment of physical activity. *Med Sci Sports Exerc.* 2004;36(3):518-24.

149. Sallis JF and Saelens BE. Assessment of physical activity by self-report: status, limitations, and future directions. *Res Q Exerc Sport.* 2000;71(2 Suppl):S1-14.

150. Sarkin JA, Nichols JF, Sallis JF, Calfas KJ. Self-report measures and scoring protocols affect prevalence estimates of meeting physical activity guidelines. *Med Sci Sports Exerc.* 2000;32(1):149-56.

151. Schmidt MD, Cleland VJ, Thomson RJ, Dwyer T, Venn AJ. A comparison of subjective and objective measures of physical activity and fitness in identifying associations with cardiometabolic risk factors. *Ann Epidemiol.* 2008;18(5):378-86.

152. Schneider PL, Crouter SE, Bassett DR. Pedometer measures of free-living physical activity: comparison of 13 models. *Med Sci Sports Exerc.* 2004;36(2):331-5.

153. Schoeller DA and van Santen E. Measurement of energy expenditure in humans by doubly labeled water method. *J Appl Physiol.* 1982;53(4):955-9.

154. Schutz Y, Weinsier RL, Hunter GR. Assessment of free-living physical activity in humans: an overview of currently available and proposed new measures. *Obes Res.* 2001;9(6):368-79.

155. Seale JL, Rumpler WV, Conway JM, Miles CW. Comparison of doubly labeled water, intake-balance, and direct- and indirect-calorimetry methods for measuring energy expenditure in adult men. *Am J Clin Nutr.* 1990;52(1):66-71.

156. Seidel HM. A Guide to Awareness and Evaluation of Humanistic Qualities in the Internist: A Special Book Review. *Developmental and Behavioral Pediatrics.* 1986;7(4):268-9.

157. Shephard RJ. Limits to the measurement of habitual physical activity by questionnaires. *Br J Sports Med.* 2003;37(3):197-206.

158. Spurr GB, Prentice AM, Murgatroyd PR, Goldberg GR, Reina JC, Christman NT. Energy expenditure from minute-by-minute heart-rate recording: comparison with indirect calorimetry. *Am J Clin Nutr.* 1988;48(3):552-9.

159. Stamatakis E, Ekelund U, Wareham NJ. Temporal trends in physical activity in England: the Health Survey for England 1991 to 2004. *Prev Med.* 2007;45(6):416-23.

160. Starling RD Use of Doubly Labeled Water and Indirect Calorimetry to Assess Physical Activity. In: Welk Geditor *Physical Activity Assessments for Health-Related Research.* Champaign: Human Kinetics; 2002. p. 197-209.

161. Strath SJ, Bassett DR, Jr., Swartz AM. Comparison of MTI accelerometer cut-points for predicting time spent in physical activity. *Int J Sports Med.* 2003;24(4):298-303.

162. Strath SJ, Swartz AM, Bassett DR, Jr., O'Brien WL, King GA, Ainsworth BE. Evaluation of heart rate as a method for assessing moderate intensity physical activity. *Med Sci Sports Exerc.* 2000;32(9 Suppl):S465-S470.

163. Sturm R. Childhood obesity - what we can learn from existing data on societal trends, part 1. *Prev Chronic Dis.* 2005a;2(1):A12.

164. Sturm R. Childhood obesity -- what we can learn from existing data on societal trends, part 2. *Prev Chronic Dis.* 2005b;2(2):A20.

165. Swartz AM, Strath SJ, Bassett DR, Jr., O'Brien WL, King GA, Ainsworth BE. Estimation of energy expenditure using CSA accelerometers at hip and wrist sites. *Med Sci Sports Exerc.* 2000;32(9 Suppl):S450-S456.

166. Sydenham PH. Structured understanding of the measurement process: Part 1: Holistic view of the measurement system. *Measurement.* 1985;3(3):115-20.

167. Sydenham PH. Relationship between measurement, knowledge and advancement. *Measurement.* 2003;34(1):3-16.

168. Thompson AM, Campagna PD, Rehman LA, Murphy RJ, Rasmussen RL, Ness GW. Physical activity and body mass index in grade 3, 7, and 11 Nova Scotia students. *Med Sci Sports Exerc.* 2005;37(11):1902-8.

169. Tremblay M, Wolfson M, Gorber SC. Canadian Health Measures Survey: rationale, background and overview. *Health Rep.* 2007a;18 Suppl:7-20.

170. Tremblay MS, Barnes JD, Copeland JL, Esliger DW. Conquering childhood inactivity: Is the answer in the past? *Med Sci Sports Exerc.* 2005b;0(0):00.

171. Tremblay MS, Barnes JD, Copeland JL, Esliger DW. Conquering childhood inactivity: is the answer in the past? *Med Sci Sports Exerc.* 2005a;37(7):1187-94.

172. Tremblay MS, Colley RC, Saunders TJ, Healy GN, Owen N. Physiological and health implications of a sedentary lifestyle. *Appl Physiol Nutr Metab.* 2010;35(6):725-40.

173. Tremblay MS, Esliger DW, Copeland JL, Barnes JD, Bassett DR. Moving forward by looking back: lessons learned from long-lost lifestyles. *Appl Physiol Nutr Metab.* 2008;33(4):836-42.

174. Tremblay MS, Esliger DW, Tremblay A, Colley R. Incidental movement, lifestyle-embedded activity and sleep: new frontiers in physical activity assessment. *Can J Public Health.* 2007b;98 Suppl 2:S208-S217.

175. Tremblay MS and Gorber SC. Canadian health measures survey: brief overview. *Can J Public Health.* 2007;98(6):453-6.

176. Tremblay MS, Leblanc AG, Janssen I, Kho ME, Hicks A, Murumets K, Colley RC, Duggan M. Canadian sedentary behaviour guidelines for children and youth. *Appl Physiol Nutr Metab.* 2011a;36(1):59-64.

177. Tremblay MS, Shephard RJ, Brawley LR. Research that informs Canada's physical activity guides: an introduction. *Can J Public Health.* 2007c;98 Suppl 2:S1-S8.

178. Tremblay MS, Warburton DE, Janssen I, Paterson DH, Latimer AE, Rhodes RE, Kho ME, Hicks A, Leblanc AG, Zehr L, Murumets K, Duggan M. New canadian physical activity guidelines. *Appl Physiol Nutr Metab.* 2011b;36(1):36-46.

179. Troiano RP. A timely meeting: objective measurement of physical activity. *Med Sci Sports Exerc.* 2005;37(11 Suppl):S487-S489.

180. Troiano RP, Berrigan D, Dodd KW, Masse LC, Tilert T, McDowell M. Physical activity in the United States measured by accelerometer. *Med Sci Sports Exerc.* 2008;40(1):181-8.

181. Troiano RP, Macera CA, Ballard-Barbash R. Be physically active each day. How can we know? *J Nutr.* 2001;131(2S-1):451S-60S.

182. Trost SG, McIver KL, Pate RR. Conducting accelerometer-based activity assessments in field-based research. *Med Sci Sports Exerc.* 2005;37(11 Suppl):S531-S543.

183. Trost SG, Pate RR, Freedson PS, Sallis JF, Taylor WC. Using objective physical activity measures with youth: how many days of monitoring are needed? *Med Sci Sports Exerc.* 2000;32(2):426-31.

184. Trost SG, Pate RR, Sallis JF, Freedson PS, Taylor WC, Dowda M, Sirard J. Age and gender differences in objectively measured physical activity in youth. *Med Sci Sports Exerc.* 2002;34(2):350-5.

185. Trost SG, Ward DS, Moorehead SM, Watson PD, Riner W, Burke JR. Validity of the computer science and applications (CSA) activity monitor in children. *Med Sci Sports Exerc.* 1998;30(4):629-33.

186. Tryon WW and Williams R. Fully proportional actigraphy: A new instrument. *Behavior Research Methods, Instruments, & Computers.* 1996;28(3):392-403.

187. Tudor-Locke C, Williams JE, Reis JP, Pluto D. Utility of pedometers for assessing physical activity: convergent validity. *Sports Med.* 2002;32(12):795-808.

188. U.S.Department of Health and Human Services. Physical Activity and Health: A Report of the Surgeon General (1st edition). 1996. McLean, Virginia, International Medical Publishing, Inc.

189. US General Accounting Office. Report by the Comptroller General of the United States, Science Indicators: Improvements Needed in Design, Construction and Interpretation. 5. 1979.

190. Van Hees V, Slootmaker SM, De GG, Van MW, Van Lummel RC. Reproducibility of a triaxial seismic accelerometer (DynaPort). *Med Sci Sports Exerc.* 2009;41(4):810-7.

191. Walcher W Measurement and the progress of knowledge in physics. In: Kramer Beditor *The Art of Measurement, Metrology in Fundamental and Applied Physics.* Weinheim, New York: VCH Verlag; 1988. p. 1-29.

192. Wang YC, Gortmaker SL, Sobol AM, Kuntz KM. Estimating the energy gap among US children: a counterfactual approach. *Pediatrics.* 2006;118(6):e1721-e1733.

193. Warburton DE, Katzmarzyk PT, Rhodes RE, Shephard RJ. Evidence-informed physical activity guidelines for Canadian adults. *Can J Public Health.* 2007;98 Suppl 2:S16-S68.

194. Warburton DE, Nicol CW, Bredin SS. Health benefits of physical activity: the evidence. *CMAJ.* 2006;174(6):801-9.

195. Ward DS, Evenson KR, Vaughn A, Rodgers AB, Troiano RP. Accelerometer use in physical activity: best practices and research recommendations. *Med Sci Sports Exerc.* 2005;37(11 Suppl):S582-S588.

196. Wareham NJ and Rennie KL. The assessment of physical activity in individuals and populations: why try to be more precise about how physical activity is assessed? *Int J Obes Relat Metab Disord.* 1998;22 Suppl 2:S30-S38.

197. Warnecke RB, Johnson TP, Chavez N, Sudman S, O'Rourke DP, Lacey L, Horm J. Improving question wording in surveys of culturally diverse populations. *Ann Epidemiol.* 1997;7(5):334-42.

198. Webb P. The measurement of energy exchange in man: an analysis. *Am J Clin Nutr.* 1980;33(6):1299-310.

199. Weir J. New methods for calculating metabolic rate with special reference to protein metabolism. *J Physiol.* 1949;109(1-2):1-9.

200. Welk G. *Physical Activity Assessments for Health-Related Research.* Champaign, IL: Human Kinetics; 2002.

201. Welk GJ. Principles of design and analyses for the calibration of accelerometry-based activity monitors. *Med Sci Sports Exerc.* 2005;37(11 Suppl):S501-S511.

202. Welk GJ, Corbin CB, Dale D. Measurement issues in the assessment of physical activity in children. *Res Q Exerc Sport.* 2000;71(2 Suppl):S59-S73.

203. Welk GJ, Eisenmann JC, Schaben J, Trost SG, Dale D. Calibration of the biotrainer pro activity monitor in children. *Pediatr Exerc Sci.* 2007;19(2):145-58.

204. West Suitor C and Kraak VI. Adequacy of evidence for physical activity guidelines development: workshop summary. Available from http://www.nap.edu/catalog/11819.html [accessed29 January 2007] . 2007.

205. Westerterp KR. Assessment of physical activity: a critical appraisal. *Eur J Appl Physiol.* 2009;105(6):823-8.

206. Wilcox S, Irwin ML, Addy C, Stolarczyk L, Ainsworth BE, Whitt M, Tudor-Locke C. Agreement between participant-rated and compendium-coded intensity of daily activities in a triethnic sample of women ages 40 years and older. *Ann Behav Med.* 2001;23(4):253-62.

207. Wilmore JH and Haskell WL. Use of the heart rate-energy expenditure relationship in the individualized prescription of exercise. *Am J Clin Nutr.* 1971;24(9):1186-92.

208. Wilson PW, Paffenbarger RS, Jr., Morris JN, Havlik RJ. Assessment methods for physical activity and physical fitness in population studies: report of a NHLBI workshop. *Am Heart J.* 1986;111(6):1177-92.

209. Wood TM. Issues and future directions in assessing physical activity: An introduction to the conference proceedings. *Res Q Exerc Sport.* 2000;71(2):ii-vii.

210. Zhang K, Pi-Sunyer FX, Boozer CN. Improving energy expenditure estimation for physical activity. *Med Sci Sports Exerc.* 2004;36(5):883-9.

211. Zhang K, Werner P, Sun M, Pi-Sunyer FX, Boozer CN. Measurement of human daily physical activity. *Obes Res.* 2003;11(1):33-40.

APPENDIX A

PHYSICAL ACTIVITY QUESTIONNAIRE FOR CHILDREN (PAQ-C)

Physical Activity Questionnaire for Children (Elementary School)

Name: ______________________ Age:__________ Sex: M______ F______

Grade:_________ Teacher:______________________

We are trying to find out about your level of physical activity from ***the last 7 days*** (in the last week). This includes sports or dance that make you sweat or make your legs feel tired, or games that make you breathe hard, like tag, skipping, running, climbing, and others.

Remember:
There are no right and wrong answers — this is not a test.
Please answer all the questions as honestly and accurately as you can — this is very important.

---

1. Physical activity in your spare time: Have you done any of the following activities in the past 7 days (last week)? If yes, how many times? (Mark only one circle per row.)

	No	1-2	3-4	5-6	7 times or more
Skipping	❍	❍	❍	❍	❍
Rowing/canoeing	❍	❍	❍	❍	❍
In-line skating	❍	❍	❍	❍	❍
Tag	❍	❍	❍	❍	❍
Walking for exercise	❍	❍	❍	❍	❍
Bicycling	❍	❍	❍	❍	❍
Jogging or running	❍	❍	❍	❍	❍
Aerobics	❍	❍	❍	❍	❍
Swimming	❍	❍	❍	❍	❍
Baseball, softball	❍	❍	❍	❍	❍
Dance	❍	❍	❍	❍	❍
Football	❍	❍	❍	❍	❍
Badminton	❍	❍	❍	❍	❍
Skateboarding	❍	❍	❍	❍	❍
Soccer	❍	❍	❍	❍	❍
Street hockey	❍	❍	❍	❍	❍
Volleyball	❍	❍	❍	❍	❍
Floor hockey	❍	❍	❍	❍	❍
Basketball	❍	❍	❍	❍	❍
Ice skating	❍	❍	❍	❍	❍
Cross-country skiing	❍	❍	❍	❍	❍
Ice hockey/ringette	❍	❍	❍	❍	❍
Other:______________________	❍	❍	❍	❍	❍
________________________	❍	❍	❍	❍	❍

2. In the last 7 days, during your physical education (PE) classes, how often were you very

active (playing hard, running, jumping, throwing)? (Check one only.)

I don't do PE ....………….. ❍
Hardly ever .... ❍
Sometimes .... ❍
Quite often .... ❍
Always .... ❍

3. In the last 7 days, what did you do most of the time *at recess*? (Check one only.)

Sat down (talking, reading, doing schoolwork)… ❍
Stood around or walked around .... ❍
Ran or played a little bit .... ❍
Ran around and played quite a bit .... ❍
Ran and played hard most of the time .... ❍

4. In the last 7 days, what did you normally do *at lunch* (besides eating lunch)? (Check one only.)

Sat down (talking, reading, doing schoolwork).. ❍
Stood around or walked around .... ❍
Ran or played a little bit .... ❍
Ran around and played quite a bit .... ❍
Ran and played hard most of the time .... ❍

5. In the last 7 days, on how many days *right after school*, did you do sports, dance, or play games in which you were very active? (Check one only.)

None .... ❍
1 time last week .... ❍
2 or 3 times last week .... ❍
4 times last week .... ❍
5 times last week .... ❍

6. In the last 7 days, on how many *evenings* did you do sports, dance, or play games in which you were very active? (Check one only.)

None .... ❍
1 time last week .... ❍
2 or 3 times last week .... ❍
4 or 5 last week .... ❍
6 or 7 times last week .... ❍

7. *On the last weekend*, how many times did you do sports, dance, or play games in which

you were very active? (Check one only.)

None .... ❍
1 time .... ❍
2 — 3 times .... ❍
4 — 5 times .... ❍
6 or more times .... ❍

8. Which *one* of the following describes you best for the last 7 days? Read *all five* statements before deciding on the *one* answer that describes you.

A. All or most of my free time was spent doing things that involve little physical effort ….. ❍

B. I sometimes (1 — 2 times last week) did physical things in my free time (e.g. played sports, went running, swimming, bike riding, did aerobics) ……………………………………….....…… ❍

C. I often (3 — 4 times last week) did physical things in my free time ……………………………………………………….........….. ❍

D. I quite often (5 — 6 times last week) did physical things in my free time……………………………………………………….…… ❍

E. I very often (7 or more times last week) did physical things in my free time ………………………………………………………………. ❍

9. Mark how often you did physical activity (like playing sports, games, doing dance, or any other physical activity) for each day last week.

	None	Little bit	Medium	Often	Very often
Monday	❍	❍	❍	❍	❍
Tuesday	❍	❍	❍	❍	❍
Wednesday	❍	❍	❍	❍	❍
Thursday	❍	❍	❍	❍	❍
Friday	❍	❍	❍	❍	❍
Saturday	❍	❍	❍	❍	❍
Sunday	❍	❍	❍	❍	❍

10. Were you sick last week, or did anything prevent you from doing your normal physical activities? (Check one.)

Yes ....……………….. ❍
No ...……….................……..................................... ❍

If Yes, what prevented you? ___________________________________

Scoring

Overall process - Find an activity score between 1 and 5 for each item (excluding item 10)

Five Easy Steps

1) *Item 1 (Spare time activity)*

- Take the mean of all activities ("no" activity being a 1, "7 times or more" being a 5) on the activity checklist to form a composite score for item 1.

2) *Items 2 to 8 (PE, recess, lunch, right after school, evening, weekends, and describes you best)*

- The answers for each item start from the lowest activity response and progress to the highest activity response

- Simply use the reported value that is checked off for each item (the lowest activity response being a 1 and the highest activity response being a 5).

3) *Item 9*

- Take the mean of all days of the week ("none" being a 1, "very often" being a 5) to form a composite score for item 9.

4) *Item 10*

- Can be used to identify students who had unusual activity during the previous week, but this question is **NOT** used as part of the summary activity score.

5) *How to calculate the final PAQ-C activity summary score* 6

Once you have a value from 1 to 5 for each of the 9 items (items 1 to 9) used in the physical activity composite score, you simply take the mean of these 9 items, which results in the final PAQ-C activity summary score.

- A score of 1 indicates low physical activity, whereas a score of 5 indicates high physical activity.

APPENDIX B

RESEARCH ETHICS APPROVAL DOCUMENTS

Research Services

Bonnie Korthuis, Administrative Assistant
University of Saskatchewan
Rm 210 Kirk Hall, 117 Science Place
SASKATOON, SK S7N 5C8 CANADA
Phone: 966-4053 Fax: 966-8597
Email: bonnie.korthuis@usask.ca

MEMORANDUM

To: Dr. Mark Tremblay and J. Barnes
College of Kinesiology

From: Bonnie Korthuis

Date: February 8, 2002

Re: **Verification of Ethics Submission**

This memorandum acknowledges that the application for ethics approval submitted by Joel Barnes and entitled, "Moving Ahead by Looking Back: A Novel Approach for Establishing Physical Activity Guidelines for Children" was received in the ethics office on Friday, February 8, 2002.

[redacted]

UNIVERSITY OF SASKATCHEWAN
BEHAVIOURAL RESEARCH ETHICS BOARD
http://www.usask.ca/research/ethics.shtml

NAME: M. Tremblay (J. Barnes) **BSC#:** 02-344
College of Kinesiology

DATE: March 8, 2002

The Behavioural Research Ethics Board has reviewed the revisions to the Application for Ethics Approval for your study "Moving Ahead by Looking Back: A Novel Approach for Establishing Physical Activity Guidelines for Children" (02-344).

1. Your study has been APPROVED.

2. Any significant changes to your proposed study should be reported to the Chair for Committee consideration in advance of its implementation.

3. The term of this approval is for 5 years.

4. This approval is valid for five years on the condition that a status report form is submitted annually to the Chair of the Committee. This certificate will automatically be invalidated if a status report form is not received within one month of the anniversary date. Please refer to the website for further instructions: http://www.usask.ca/research/ethics.shtml

I wish you a successful and informative study.

Dr. Valerie Thompson, Chair
Behavioural Research Ethics Board

VT/bk

UNIVERSITY OF SASKATCHEWAN
BEHAVIOURAL RESEARCH ETHICS BOARD
http://www.usask.ca/research/ethics.shtml

NAME: Mark Tremblay **Beh# 05-27**
Kinesiology

DATE: April 4th, 2005

The University of Saskatchewan Behavioural Research Ethics Board has reviewed the Application for Ethics Approval for your study "Moving Ahead by Looking Further Back: A Novel Approach for Establishing Physical Activity Guidelines for Children" (Beh 05-27). Thank you for making the requested modifications.

1. Your study has been APPROVED.

2. Any significant changes to your proposed method, or your consent and recruitment procedures should be reported to the Chair for Research Ethics Board consideration in advance of its implementation.

3. The term of this approval is for 5 years.

4. This approval is valid for one year. A status report form must be submitted annually to the Chair of the Research Ethics Board in order to extend approval. This certificate will automatically be invalidated if a status report form is not received within one month of the anniversary date. Please refer to the website for further instructions http://www.usask.ca/research/behavrsc.shtml

I wish you a successful and informative study.

[redacted]

Dr. Valerie Thompson, Chair
University of Saskatchewan
Behavioural Research Ethics Board

VT/cc

Office of Research Services, University of Saskatchewan
Room 1607, 110 Gymnasium Place, Box 5000 RPO University, Saskatoon SK S7N 4J8 CANADA
Telephone: (306) 966-8576 Facsimile: (306) 966-8597
http://www.usask.ca/research

UT

THE UNIVERSITY of TENNESSEE

Institutional Review Board

Office of Research
1534 White Avenue
Knoxville, Tennessee 37996-1529
Phone: (865) 974-3466
Fax: (865) 974-7400

04/01/2005

IRB#: 6786B

TITLE: Walking and Physical Fitness in Amish Children

Bassett, Jr., David R.
Exercise, Sport & Leisure Studies
1914 Andy Holt Ave.
Campus

Tremblay, Mark, Co-PI
College of Kinesiology
Saskatoon, SK 57N 5C2
CANADA

This is to inform you that your Form D request for modification in the above protocol has been approved. This approval does not affect the original approval date.

Responsibilities of the investigator during the conduct of this project include the following:

1. To obtain prior approval from the Committee before instituting any changes in the project.

2. To retain signed consent forms from subjects for at least three years following completion of the project.

3. To submit a Form D to report changes in the project or to report termination at 12-month or less intervals.

We wish you continued success in your research endeavor.

Sincerely,

[redacted]

Brenda Lawson
Compliances

University of Saskatchewan Research Ethics Board (Behavioural)
Room 306 Kirk Hall
117 Science Place
SASKATOON SK S7N 5C8

Investing in Ideas
U OF S RESEARCH

STATUS REPORT FORM

This form is submitted for the following purpose

_____ Annual status report.

X Notice of study closure. When was the ethics approval for this study due to expire? Expiry Date: March 1, 2006

The ongoing review requirement stipulated that a status report must be submitted within the one year anniversary date of: ____________________

Report Prepared by: Mark Tremblay   Date: February 14, 2006

1. PRINCIPAL INVESTIGATOR

Mark Tremblay

2. DEPARTMENT/DIVISION	**3. Beh/BSC #**
Kinesiology	**Beh#05-27**

4. TITLE OF STUDY

"Moving Ahead by Looking FURTHER Back: A Novel Approach for Establishing Physical Activity Guidelines for Children"

5. SPONSOR (where applicable)

6. BRIEF SUMMARY OF PROGRESS OF STUDY (projected completion date for recruitment and data collection, number of subjects admitted to date, target enrollment, anticipated end-date).

All 139 eligible participants participated in the study. The data collection for this project was completed in May, 2006. Since then we have been performing data cleaning, analysis and writing. A final report was prepared for the Amish community and individual reports were prepared for each of the study participants. The study data are secure. We are currently preparing abstracts (presentations) and two manuscripts based on this research project. For the purposes of the REB this file can be closed.

7. ARE THERE ANY ASPECTS OF THIS STUDY WHICH SHOULD BE BROUGHT TO THE ATTENTION OF THE Beh-REB (i.e. Was there any difficulty implementing the project as planned, were there any complaints from research participants or did they experience any unexpected emotional distress? Were there any other ethical concerns) ? **Note: Please attach additional pages as needed.**

No. This study was completed without incident and all data collection procedures went well. The participants (and researchers for that matter!) thoroughly enjoyed the study. We have debriefed with our contact in the Amish community, we have sent a research summary to the community, and we provided individual reports for each of the participants.

8. PRINCIPAL INVESTIGATOR

[redacted]
Signature   Date: February 14, 2006

ONGOING REVIEW REQUIREMENTS: This status report is valid for up to one year. The REB will require the submission of an annual status report within one month of the anniversary date. Please note if the Status Report Form is not submitted by the one-year anniversary date, the ethics certificate will automatically be invalidated.

For Administrative Use Only:

Approved On: 20-Feb-2006   Expiry Date: NA

Signature of Chair or designate: [redacted]

June 2002

APPENDIX C

CONSENT FORMS AND PHYSICAL ACTIVITY READINESS QUESTIONNAIRE

(PAR-Q)

Joel David Barnes
University of Saskatchewan
105 Gymnasium Place
Saskatoon, SK S7N 5C2
(306) 651-7061

Dear Parent/Guardian,

Many Canadian children today are physically inactive. One explanation for this phenomenon is technology. Children spend hours playing video games and watching television every day. As a result, obesity in Canadian children is on the rise.

Health Canada has given us a grant so that we can compare physical activity between children aged 9 – 12 years in Saskatchewan with similar-aged children from your community in Ontario. What we expect to find is that children in your community are more physically active than children in Saskatchewan because of lifestyle differences. For example, the lifestyle of children in Saskatchewan is influenced by technology to a greater extent than it is in children from your community.

Since the spring of 2002, we have been in contact with Mr. Levi Frey who lives in your community. We have informed him about our research project. He is in support of the project and he has agreed to let us contact you on an individual basis.

The information from this research project will be useful in our attempt to promote physical activity among Canadian children. It will help us demonstrate the need for children to reduce their use of technology as part of maintaining a physically active lifestyle.

In order for your children to participate in this project, they must be between 9 and 12 years old and willing to complete a fitness test that includes height and weight measurements, push-ups, sit-ups and so on. The fitness test will be done in the house where the children live and should take about 30 minutes for one child to complete. Also, a small device must be worn on one side of the hip for seven days following the fitness test. This device is called an accelerometer and measures physical activity. After seven days when we return for the accelerometer, a questionnaire measuring physical activity must be completed. The questionnaire should take between 10 and 15 minutes to fill out. Next summer, the accelerometer must be worn for an additional seven days followed by the completion of the same physical activity questionnaire.

Each child who participates will receive $10 this fall and $10 again next summer for their participation.

We would appreciate it if you would read and fill out the attached consent form and the PAR-Q questionnaire, and then mail them back to us using the self-addressed stamped envelope enclosed. Your prompt attention to this would be appreciated. The Research Assistants for this project will be moving to Mount Forest in the middle of September and would like to begin the testing as soon as possible. Thank you for you consideration of this request.

We look forward to hearing from you.

Sincerely,

[redacted]

Joel Barnes

College of Kinesiology, University of Saskatchewan
105 Gymnasium Place, Saskatoon SK S7N 5C2 Canada Telephone: (306) 966-6500 Facsimile: (306) 966-6464

Moving Ahead by Looking Back: A Novel Approach for Establishing Physical Activity Guidelines for Children

Parent and Guardian Information and Consent Form

Principal Investigator:

Dr. Mark Tremblay
College of Kinesiology
University of Saskatchewan
(306) 966-6484

Research Assistant:

Joel Barnes
College of Kinesiology
University of Saskatchewan
(306) 242-3961

College of Kinesiology, University of Saskatchewan
105 Gymnasium Place, Saskatoon SK S7N 5C2 Canada Telephone: (306) 966-6500 Facsimile: (306) 966-6464

The purpose of this study is to assess and compare the fitness and physical activity levels of children from an Old Order Mennonite community with a group of children from Saskatchewan sharing a similar rural environment. This will assist in establishing healthy physical activity guidelines by comparing a lifestyle similar to years gone by, with that of today.

In addition to assisting in the establishment of physical activity guidelines for children, you stand to benefit from this research project on a personal level. Each participant will receive the results of the fitness appraisal. These results could help to identify areas where the participant could benefit from additional physical activity. None of these benefits are guaranteed.

The fitness level of participants will be determined using a standard battery of fitness tests. (Blood pressure, heart rate, height, weight, waist girth, triceps skinfold, grip strength, push-ups, sit and reach flexibility, partial curl-ups, and a test of aerobic fitness). These tests are commonly used and produce no risk greater than performing regular physical activity. Normal sensations associated with normal physical exertion such as fatigue, mild nausea, "rubbery" legs, and possible slight dizziness should be expected. Prior to any testing the participants would be required to complete the Physical Activity Readiness Questionnaire (PAR-Q), which serves as a screening tool. This battery of tests has been administered to over a million Canadians without any recorded serious incidents. The investigator has administered or overseen thousands of these test, without incident. The time commitment for this portion of the research project is one hour.

The physical activity level of participants will be determined using a small activity monitor that is worn on a belt for seven consecutive days. Since this will be carried out on two separate occasions, each participant will wear the device for 14 days, but the only inconvenience is putting on and taking off the device. Physical activity will also be assessed by having the participants complete a self-reported physical activity questionnaire. The time commitment involved is between 10 and 15 minutes.

The participants will be identified by an ID number in order to protect their anonymity and right of privacy. No personal information other than age and sex will be recorded. Address information will be collected so that the summary results can be mailed out after the study is complete. All reported data will use ID numbers and in most cases grouped data will be reported.

The findings from this study will be reported in one or more masters theses as well as several research papers and presentations. All participants will be mailed a short summary of the findings with only grouped data presented to preserve anonymity. Upon completion of the individual fitness testing, participants will be given their individual results for their own interest or records.

Your participation in this research project is completely voluntary and should you wish, you may withdraw from participating at any time without fear of reprisal.

If you have any concerns or questions regarding this research project, feel free to contact the principal investigator, Dr. Mark Tremblay (306-966-6484), the research assistant, Joel Barnes (306-242-3961), or the Office of Research Services at the University of Saskatchewan (306-966-4053).

This research project was reviewed and approved on ethical grounds by the University of Saskatchewan Advisory Committee on Ethics in Behavioural Science Research on March 8, 2002.

Moving Ahead by Looking Back: A Novel Approach for Establishing Physical Activity Guidelines for Children

University of Saskatchewan
Parent and Guardian Information and Consent Form

This Parent/Guardian Authorization form is being sent to you to obtain your permission in allowing your child to participate in the research study titled **Moving Ahead by Looking Back: A Novel Approach for Establishing Physical Activity Guidelines for Children**. The testing will be overseen by Dr. Mark Tremblay. For more information contact Dr. Tremblay at (306) 966-6484. Your participation in this project is greatly appreciated.

Parent's Name: ________________________________

Child's Name: ________________________________

School: ________________________________

Home Address: ________________________________

________________________________ Postal Code:____________

Phone:____________ Birthdate: _________

Please identify any medical or health conditions that the researchers should be aware of, including the use of any medications:

____

CONSENT
I acknowledge that:

1. Based on my knowledge there is no medical reason why my child cannot perform the testing
2. My child has completed the PAR-Q and none of the responses were "yes"
3. I have reported any medication that my child is taking
4. The researchers have answered all of my questions
5. I understand the potential risks and benefits of these procedures
6. All of the results will be kept strictly confidential and if used for publication, identities will remain anonymous
7. I recognize that my child's involvement is voluntary and they may discontinue the testing at any time.

Parent's Name:_______________ Signature of Parent:________________ Date: ________

Child's Name:_______________ Signature of Child:________________ Date: ________

CONSENT FORM

Walking and Physical Fitness in Amish Children

Researchers:

David R. Bassett, Jr.
University of Tennessee
Dept. of Exercise, Sport, & Leisure
1914 Andy Holt Ave.
Knoxville, TN 37919
U.S.A.
Telephone: 865-974-8766

Mark Tremblay
University of Saskatchewan
College of Kinesiology
105 Gymnasium Place
Saskatoon, SK S7N 5C2
Canada
Telephone: 613-951-4385

Purpose

Your child is invited to take part in a research study. The purpose of the study is to learn how much walking Amish children do each day. We also want to measure their physical fitness.

Procedures

The testing will take place at your child's school, during regular school hours or after school. Children will be asked their age and grade in school. Height, weight, and skinfold thickness on the back of their arm will be measured.

Physical Fitness Measures

Measurements of the children's physical fitness will be made. They will squeeze a metal device to measure handgrip strength. They will sit on the floor with legs straight and try to touch their toes to measure flexibility. They will also step up-and-down on a bench for 3-4 minutes, after which their pulse rate will be measured. We have been performing these tests for years on children across Canada with no harmful outcomes. In all, this study will take less than an hour including providing a short description of the fitness results.

Step counter and Activity meter

Your child will be loaned a step counter and an activity meter. The step counter is to be worn each day for 7 days. We will use it to see how far your child walks. The activity meter tells the number of minutes spent in light, moderate, or strenuous exercise. These must be returned at the end of the study. The daily step counts will be provided to each child at the end of the study, but the activity monitor information requires extensive calculations and will not be shared with the children.

Risks and Benefits

There are few risks to being in this study; your child could strain a muscle or have an abnormal heart rate or blood pressure response during the fitness test. We will try not to let those things occur. The results will help us to understand the effects of technology on walking and physical fitness.

Confidential

The information from these tests will be treated as private and will not be shown to any person without your consent. The numbers may be used in research reports and/or journals but your child's name will not be used, only grouped data will be reported.

Right to Ask Questions and to Withdraw
Your child is free to decide whether or not to be in this study and may withdraw from the study at any time. At any time before, during, or after this study if you have questions please feel free to contact us (contact information above).

Consent
The proposed research project was reviewed and approved by the University of Tennessee Institutional Review Board on February 8, 2005 and the University of Saskatchewan Behavioural Sciences Research Ethics Board on March 14th,. If you have any questions concerning the study or the rights of the participant, you may call the Office of Research Services, University of Saskatchewan collect at (306) 966-2084.

By signing this paper, I am indicating that I understand and agree to let my child (or children) take part in this study.

______________________________ _______________
Your signature Date

______________________________ _______________
Researcher's signature Date

Child's Assent Form

Walking and Physical Fitness in Amish Children

You are invited to take part in a study. We want to learn how far Amish children walk each day. We also want to measure your physical fitness.

The study

The study will take place at school. We will ask how old you are and what grade you are in. We will also measure how tall you are, how much you weigh, and the thickness of the skin on your arm. We will see how strong and fit you are. First, you will squeeze something to see how strong your hands are. You will sit on the floor with legs straight and try to touch your toes. Then you will step up-and-down on a bench for several minutes. The overall time required will be less than an hour.

You will then wear a step counter and an activity meter for 7 days. Each day in school, we will open the step counter and see how far you have walked. The devices must be returned at the end of the study.

Risks and Benefits

There are few risks to being in this study; you could strain a muscle or have a strange heart rate or blood pressure responses during the fitness test. We will try not to let those things occur. This study will tell us how far Amish children walk and how physically fit they are.

Keeping it Secret

Your test results will be kept secret and will not be shown to other people, unless you say so. The numbers for the entire group will be used in reports but your name will not be used

Right to Ask Questions and to Quit the Study

You can decide if you want to be in this study and you are free to get out of the study at any time and we will not be upset. Before you sign this form, do you have questions?

Consent

By signing this paper, I agree to be in the study.

________________________________ ____________________

Your signature (or initials) Date

Physical Activity Readiness Questionnaire - PAR-Q (revised 1994)

PAR - Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	1.	Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?
☐	☐	2.	Do you feel pain in your chest when you do physical activity?
☐	☐	3.	In the past month, have you had chest pain when you were not doing physical activity?
☐	☐	4.	Do you lose your balance because of dizziness or do you ever lose consciousness?
☐	☐	5.	Do you have a bone or joint problem that could be made worse by a change in your physical activity?
☐	☐	6.	Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
☐	☐	7.	Do you know of any other reason why you should not do physical activity?

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active — begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal — this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever — wait until you feel better; or
- if you are or may be pregnant — talk to your doctor before you start becoming more active.

Please note: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

You are encouraged to copy the PAR-Q but only if you use the entire form

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction.

NAME ______________________________

SIGNATURE ______________________________ DATE ______________________

SIGNATURE OF PARENT ______________________________ WITNESS ______________________
or GUARDIAN (for participants under the age of majority)

continued on other side...

Supported by: Health Canada Santé Canada

...continued from other side

PAR - Q & YOU

Physical Activity Readiness Questionnaire - PAR-Q (revised 1994)

We know that being physically active provides benefits for all of us. Not being physically active is recognized by the Heart and Stroke Foundation of Canada as one of the four modifiable primary risk factors for coronary heart disease (along with high blood pressure, high blood cholesterol, and smoking). People are physically active for many reasons — play, work, competition, health, creativity, enjoying the outdoors, being with friends. There are also as many ways of being active as there are reasons. What we choose to do depends on our own abilities and desires. No matter what the reason or type of activity, physical activity can improve our well-being and quality of life. Well-being can also be enhanced by integrating physical activity with enjoyable healthy eating and positive self and body image. Together, all three equal VITALITY. So take a fresh approach to living. Check out the VITALITY tips below!

Active Living:
- accumulate 30 minutes or more of moderate physical activity most days of the week
- take the stairs instead of an elevator
- get off the bus early and walk home
- join friends in a sport activity
- take the dog for a walk with the family
- follow a fitness program

Healthy Eating:
- follow Canada's Food Guide to Healthy Eating
- enjoy a variety of foods
- emphasize cereals, breads, other grain products, vegetables and fruit
- choose lower-fat dairy products, leaner meats and foods prepared with little or no fat
- achieve and maintain a healthy body weight by enjoying regular physical activity and healthy eating
- limit salt, alcohol and caffeine
- don't give up foods you enjoy — aim for moderation and variety

Positive Self and Body Image:
- accept who you are and how you look
- remember, a healthy weight range is one that is realistic for your own body make-up (body fat levels should neither be too high nor too low)
- try a new challenge
- compliment yourself
- reflect positively on your abilities
- laugh a lot

Enjoy eating well, being active and feeling good about yourself. That's VITALITY.

FITNESS AND HEALTH PROFESSIONALS MAY BE INTERESTED IN THE INFORMATION BELOW.

The following companion forms are available for doctors' use by contacting the Canadian Society for Exercise Physiology (address below):

The **Physical Activity Readiness Medical Examination (PARmed-X)** - to be used by doctors with people who answer YES to one or more questions on the PAR-Q.

The **Physical Activity Readiness Medical Examination for Pregnancy (PARmed-X for PREGNANCY)** - to be used by doctors with pregnant patients who wish to become more active.

References:

Arraix, G.A., Wigle, D.T., Mao, Y. (1992). Risk Assessment of Physical Activity and Physical Fitness in the Canada Health Survey Follow-Up Study. **J. Clin. Epidemiol.** 45:4 419-428.

Mottola, M., Wolfe, L.A. (1994). Active Living and Pregnancy, In: A. Quinney, L. Gauvin, T. Wall (eds.), **Toward Active Living: Proceedings of the International Conference on Physical Activity, Fitness and Health**. Champaign, IL: Human Kinetics.

PAR-Q Validation Report, British Columbia Ministry of Health, 1978.

Thomas, S., Reading, J., Shephard, R.J. (1992). Revision of the Physical Activity Readiness Questionnaire (PAR-Q). **Can. J. Spt. Sci.** 17:4 338-345.

***To order multiple printed copies of the PAR-Q**, please contact the*

Canadian Society for Exercise Physiology
185 Somerset St. West, Suite 202
Ottawa, Ontario CANADA K2P 0J2
Tel. (613) 234-3755 FAX: (613) 234-3565

The original PAR-Q was developed by the British Columbia Ministry of Health. It has been revised by an Expert Advisory Committee assembled by the Canadian Society for Exercise Physiology and Fitness Canada (1994).

Disponible en français sous le titre «Questionnaire sur l'aptitude à l'activité physique - Q-AAP (revisé 1994)».

Supported by: Health Canada Santé Canada

APPENDIX D

KineSoft USER MANUAL

KineSoft User Manual

Version 3.3.48

Prepared by

Dale Esliger

and

Eric Finley

1

Preface

The development of KineSoft Software began back in 2001 while Dale was working as a research assistant at the University of New Brunswick for Dr. Mark Tremblay and Dr. Jennifer Copeland (then a PhD candidate). My task was to help analyze Actigraph 7164 data to profile the physical activity behaviours of a sample of women aged 19-69 (i.e., to better understand when and how they were accumulating their physical activity). It became clear early on that data mining software was lacking for these relatively new accelerometer sensors. As a non-programmer, Dale began to explore Microsoft Visual Basic (essentially via Excel macros) as a platform to perform the calculation of outcome variables Dale was interested in. However, it became clear early on that such a platform was not powerful enough to keep pace with our research group's evolving desire for more comprehensive outcome variables.

In 2002 Dale moved to Saskatchewan to pursue a PhD with Dr. Mark Tremblay in the area of Physical Activity Measurement. By the spring of 2003 Dale began to seek out a professional programmer in order to move beyond simple outcome variables. By the winter of 2003 Dale had found and commissioned a professor in Computer Science at the University of Saskatchewan to convert his initial code into a much more robust program. The cost for this software commissioning was paid for from a research grant. The new Java based software simply called KACC (for Kinesiology Accelerometer) was delivered in beta format in February, 2004 and worked wonderfully. However, because the code was being maintained externally (i.e., although Dale owned the intellectual property, the programmer owned the code), every time Dale wanted to tweak the code or add new features he needed to find funds to pay for the work. This fee-for-service relationship was maintained for about two years until May 2006 when the final KACC update was received. Although the relationship worked well, it was clear that the costs were becoming prohibitive and the turn-around time for software updates was too slow.

In late spring 2006 Dale made the decision to sever ties with my KACC software programmer, opting instead to take his original visual basic code to a long time friend (Eric Finley) who was a computer programmer. Dale and Eric formed a partnership (Dale wrote the specifications and Eric wrote the code) and in so doing, re-establish a Java based software for analyzing accelerometer data. By the summer of 2006 Dale and Eric had launched the first version of what is now KineSoft and began selling it publically. Since that time they have developed a web presence (**www.kinesoft.org**) and sold versions of KineSoft to over 20 different research groups in four countries (**www.kinesoft.org/index.php?page=user_map**). To date they have chosen to invest the proceeds from KineSoft sales back into the program to help both refine and evolve this important analytical tool. We hope you find KineSoft useful for your research.

Sincerely,

Dale Esliger & Eric Finley

2

Table of Contents

1.0 Opening KineSoft

Simply double-click the desktop icon (Figure 1) to open the program. While the program loads the splash screen (Figure 2) will be displayed.

Figure . Desktop icon

Figure . Splash screen

Note: the program loads fairly quickly so this splash screen may not linger long.

1.1 Process Center

Once the program is loaded the following the main KineSoft user interface appears called the Process Center (Figure 3). The Process Center is set up in recognizable windows format with the following features:

i) drop down menus along the top
ii) one advanced function accessible by the icon under the drop down menus
iii) a settings section with red option buttons along the left margin (each option button has a red/green indicator light to let the user know if that feature is configured (red=no green=yes))
iv) a Pre-Processed pane on the left and a Post-Processed pane
v) at the bottom is a comprehensive graphing tool called InstaGraph.

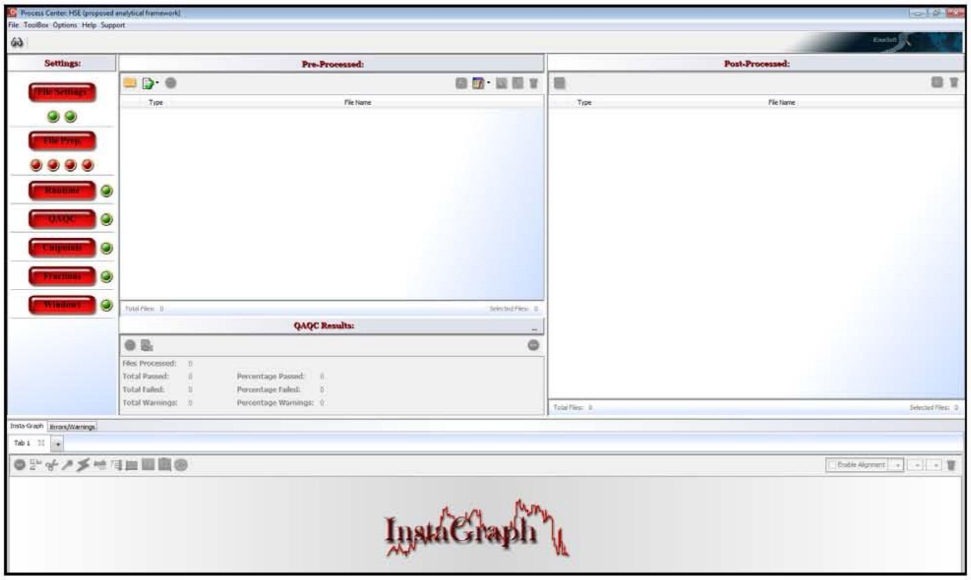


Figure . Process Center

The drop-down menus have the following options:

1.2 Drop-down Menus

Drop down menu one (Figure 4) has 7 options:

i) **Select Files**- opens up a file browse window so the user can find and select files to load into the program. This can also be achieved by clicking on the manila file folder to the right of the File drop-down menu.

ii) **Save Workspace**- allows the user to save updates to the settings to the currently loaded workspace under the existing name.

iii) **Save Workspace as**- allows the user to save the current workspace with a new archive name.

iv) **Load Workspace**- allows the user to load any previously saved workspace setups which effectively archive all the settings you normally use to analyze that particular dataset (Figure 5)

v) **Rename Workspace**- allows the user to change the name of any given workspace.

vi) **Delete Workspace**- allows the user to delete a saved workspace that is no longer required

vii) **Exit**- exits the user out of the drop-down menu

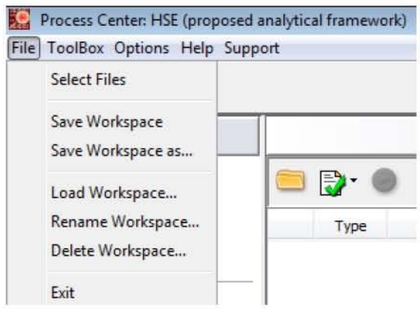


Figure . Drop-down menu one listing **7** user options

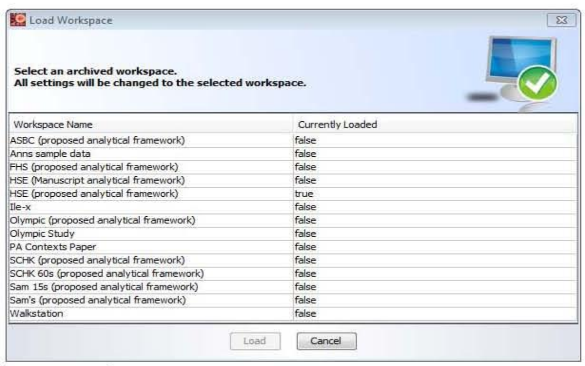


Figure . Load workspace option screen
Note: The Currently loaded column informs the user as to which workspace is currently loaded by indicating true or false.

Drop down menu two (Figure 6) has 3 options:

i) **Epoch Conversion**- allows the user to open up a self contained piece of software that will convert raw accelerometer data into files with different epochs (i.e., raw data can integrate up or down). This software tool has its own internal help guide.

ii) **NHANES Reconstitutor**- allows the user to open up a very simple self contained piece of software that will read-in raw NHANES data downloaded in .csv format from the NCHS website and will reconstitute raw .dat files complete with header so they can be analyzed using KineSoft. This new tool does not have an internal help guide; however, user instructions can be found in APPENDIX A.

iii) **File Replicator**- allows the user to open up a self contained piece of software that will replicate raw accelerometer data files (.dat or .awc). This tool is designed to allow for the selection of raw accelerometer files with specific characteristics e.g., select files by gender, age, weight, date, etc.. This tool will also allow the user to remove sensitive identifiable information from the raw data file headers using batch functionalities. This software tool has its own internal help guide.

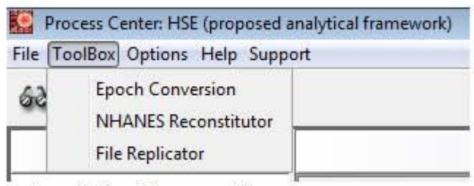


Figure . Drop-down menu two listing 3 user options

Drop-down menu three (Figure 7) has 3 options:

i) **Output Configuration**- allows the user to change the way i) dates are displayed in the reports; ii) QAQC report outcomes are sorted; iii) Bout Ranking outcomes are sorted (Figure 8).

ii) **Graph Configuration**- allows the user to change the color of the graphed elements (Figure 9). This functionality is most useful for those using the overlay graphs.

iii) **Advanced Configuration**- allows the user to change the location of the temporary file storage (Figure 10).
Note: KineSoft writes files to a temporary directory for many reasons during program execution. The default location is set to your users default temp directory; however, depending on your computer's configuration, it may be beneficial to change this location (usually for performance reasons). For instance, if you have a secondary hard drive which is a solid state drive, you will likely gain significant performance improvements by changing this directory to a dedicated directory on the solid state drive. Please note that any directory you choose will have a subfolder automatically created named 'KineSoft'.

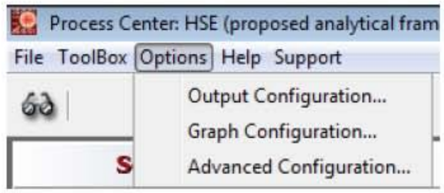


Figure . Drop-down menu three listing 3 user options

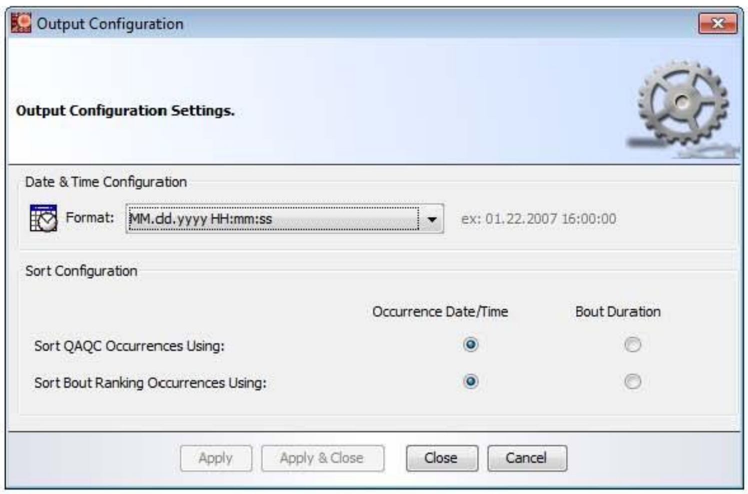


Figure . Output configuration user screen

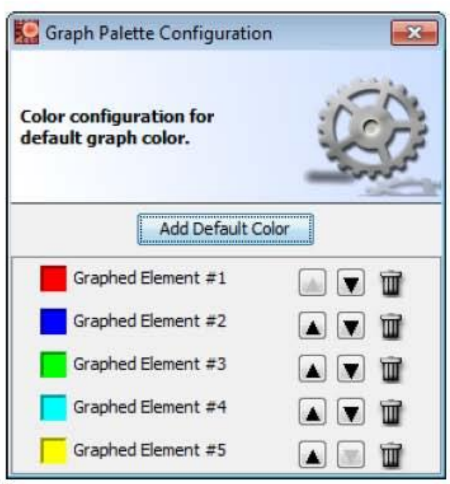


Figure . Graph configuration user screen

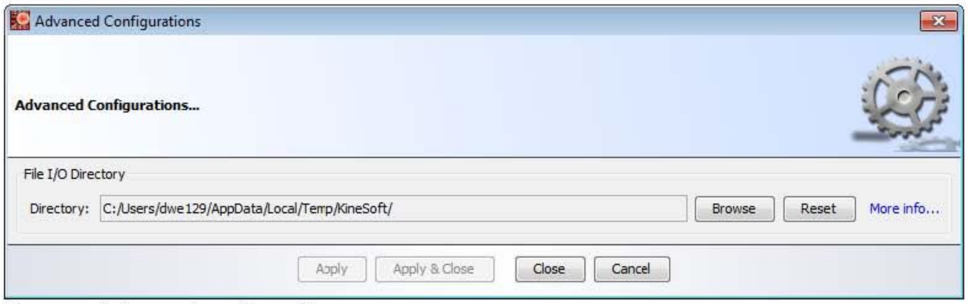


Figure . Advanced configuration user screen

Drop-down menu four (Figure 11) has 7 options:

i) **Info**- opens up a pop-up window that indicates the current version information (Figure 12).

ii) **PC Requirements**- opens a one page PDF document listing the computer software and hardware requirements for optimal performance of KineSoft (APPENDIX B).

iii) **Install & GUI Instructions**- opens a multipage PDF document outlining the instructions for installing KineSoft, complete with FTP server GUI instructions (APPENDIX C).

iv) **Version Control/Update Manager**- clicking this option results in an FTP server connection where the user's software version is checked against the KineSoft server to see if there is an update available (Figure 13).

v) **View Version History**- opens a pop-up window that provides a detailed chronology of all the KineSoft updates since version 3.2.35 (Figure 14).

vi) **About the Developers**- opens a PDF document that provides a brief background of the KineSoft developers (APPENDIX D).

vii) **User Guide**- opens this User Guide in PDF format which provides a series of screen images complete with captioned explanations of the various features.

9

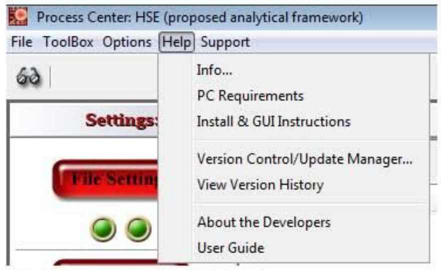


Figure . Drop-down menu four listing 7 user options

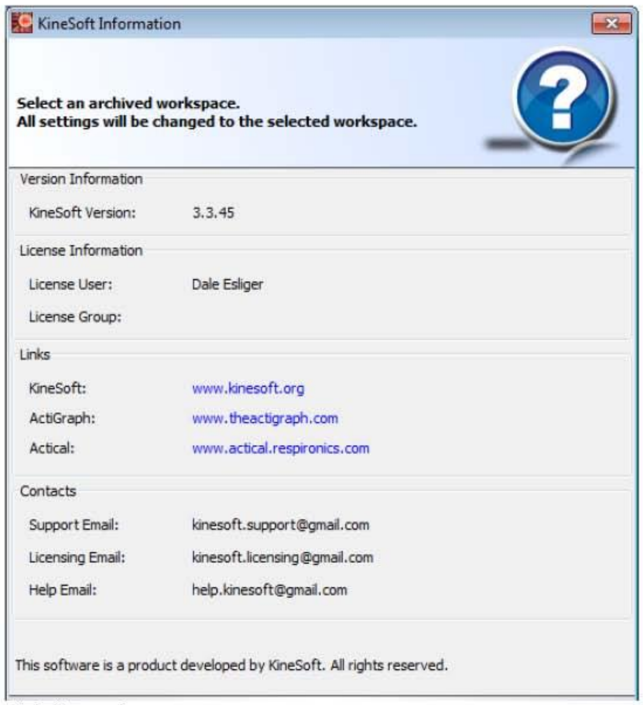


Figure . KineSoft information pop-up screen

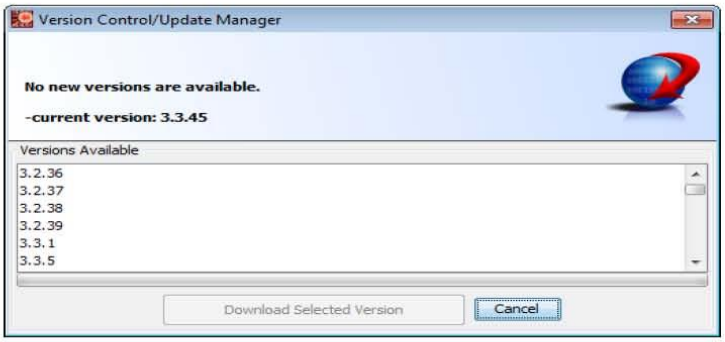


Figure . Version control / update manager pop-up screen

Note: The user has the option of rolling back to a previous version of KineSoft if they wish.

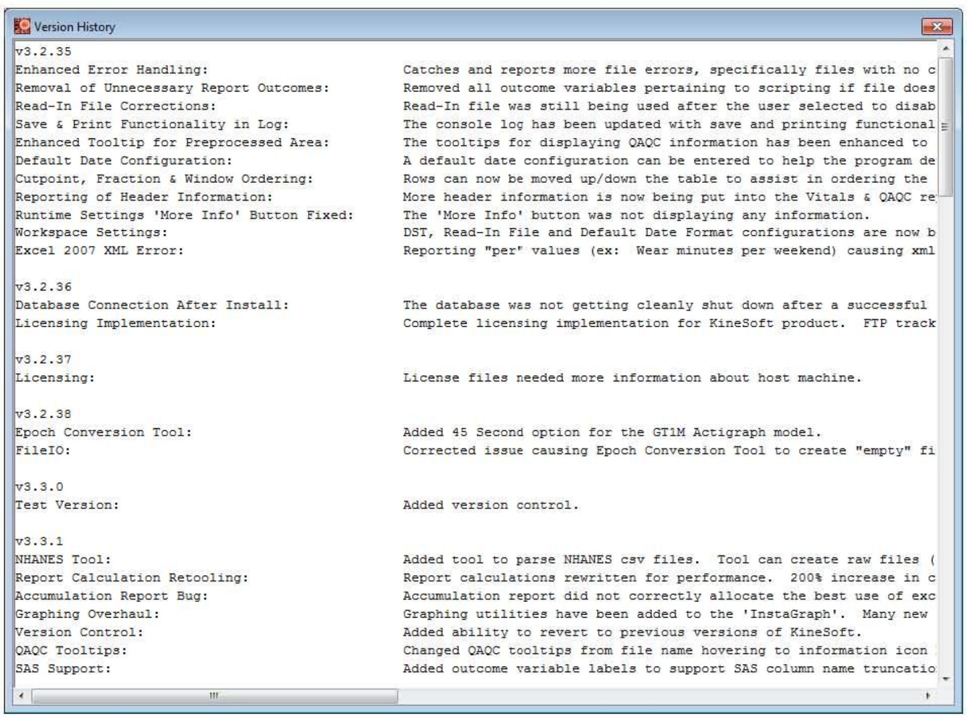


Figure . Version history pop-up screen

Drop-down menu five (Figure 15) has 2 options:

i) **Email Help**- opens up an email window so the user can easily address questions related to accelerometry, PA measurement, etc. to Dale Esliger (Figure 16).

ii) **Email Software Support**- opens up an email window so the user can easily address questions related to KineSoft technical software issues/bugs to Eric Finley (Figure 17).

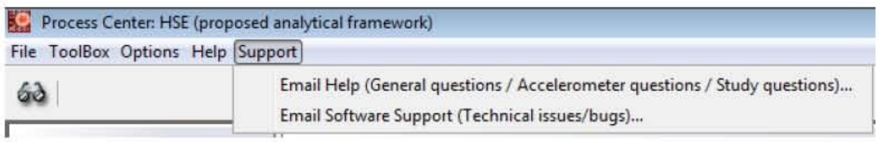


Figure . Drop-down menu five listing 2 user options

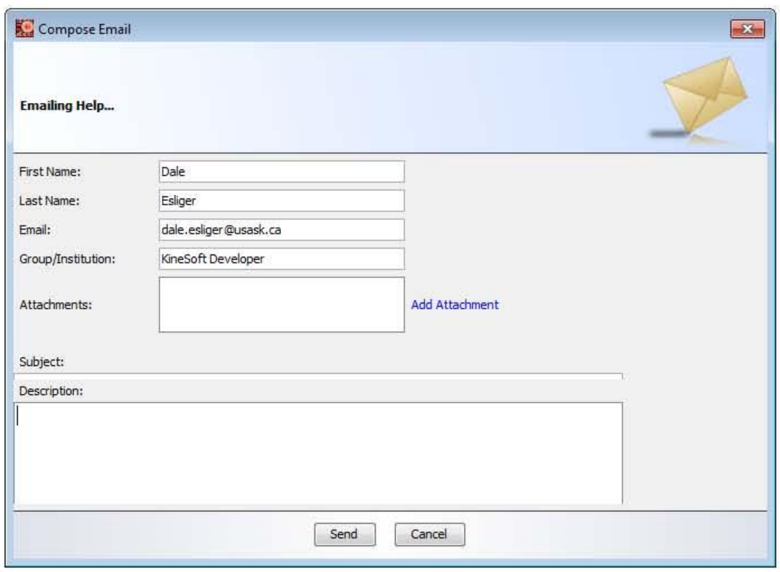


Figure . User pop-up screen used to contact Dale Esliger
Note: The first four input boxes will be auto filled with the specific user's information. The user need only type their message with or without an attachment.

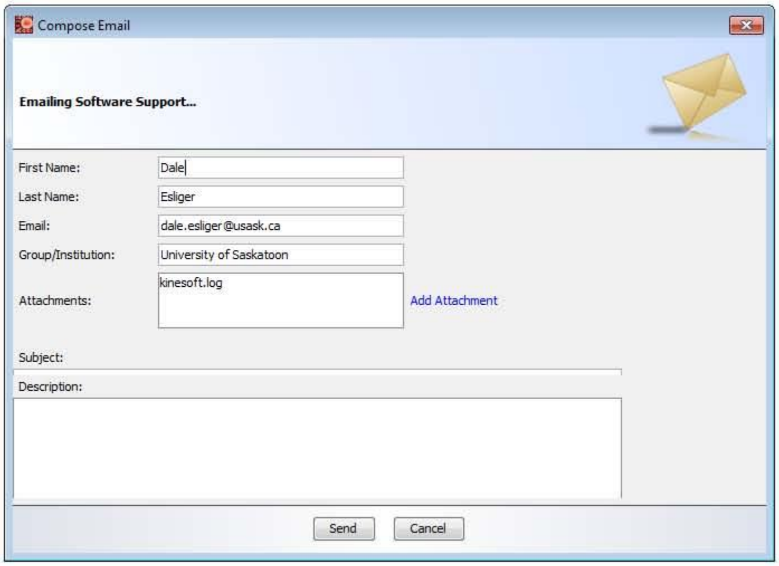


Figure . User pop-up screen used to contact Eric Finley
Note: The first four input boxes will be auto filled with the specific user's information. The user need only type their message. A status log from the user's PC will be automatically attached to the email to assist with troubleshooting.

2.0 Settings: Red Option Buttons

The red option buttons that line the left margin of the Process Center allow the user to select user-defined inputs which will guide their analyses. Selecting the input choices is a vital step in the analytical processing of accelerometer data and should be done by an informed user. Please note that all user inputs are recorded in the back end reports in an Excel worksheet labelled 'Vitals'. Each of the red buttons in the Settings section have indicator lights that allow the user to know whether that specific feature has been configured (green=yes; red=no).

2.1 File Settings button

Selecting the File Settings button opens a pop-up window with two input tabs: i) Settings; ii) Daylight Savings Time (DST) (Figure 18).

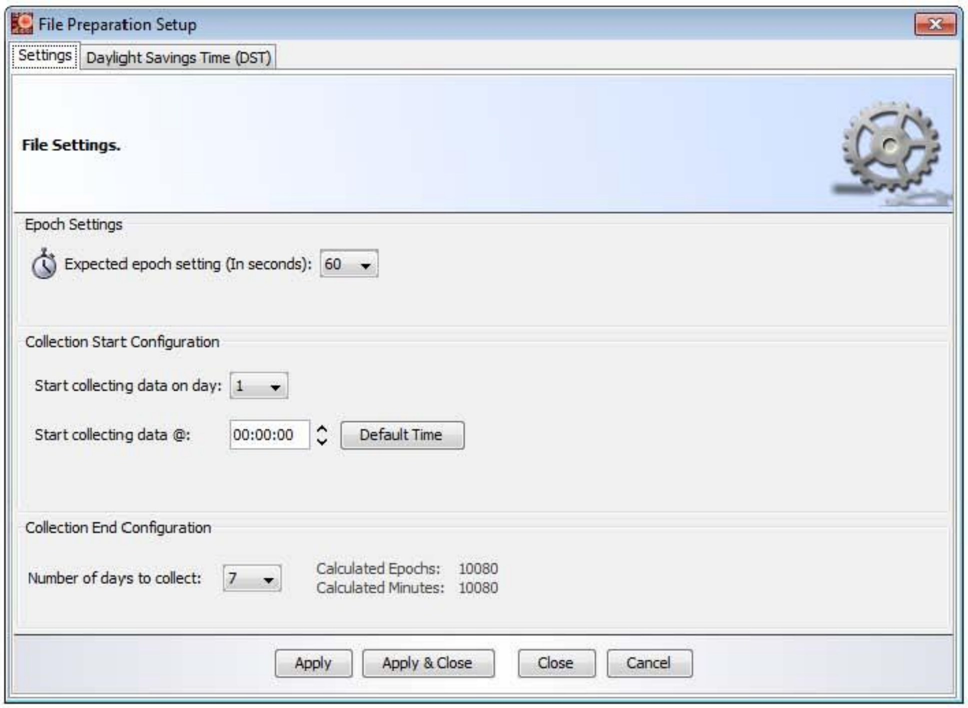


Figure . File Settings pop-up window

On the <u>first tab titled Settings</u>, there are 3 inputs to configure: i) Epoch Setting; ii) Start Day and Time; iii) Number of days to analyze.

Epoch Setting- from the drop down menu select the epoch duration that matches the raw data you wish to process

Start collecting data on day- from the drop down menu select which day you wish the analyses to start on (usually day 1; unless for example, you mailed the monitor to the participant). Also, be sure to set the expected start time on the start day. If the start times differ, simply select the most common start time.

Collection End Configuration- from the drop down menu select how many days you want to analyze (often 7 days for week long studies).

Note: Once you have chosen you options be sure to use the apply button to save your selections.

On the <u>second tab titled Daylight Saving Time</u>, there are 3 user input options to be configured (Figure 19): i) Time Zone; ii) Treatment for DST/ST beginning; iii) Treatment for DST/ST ending.

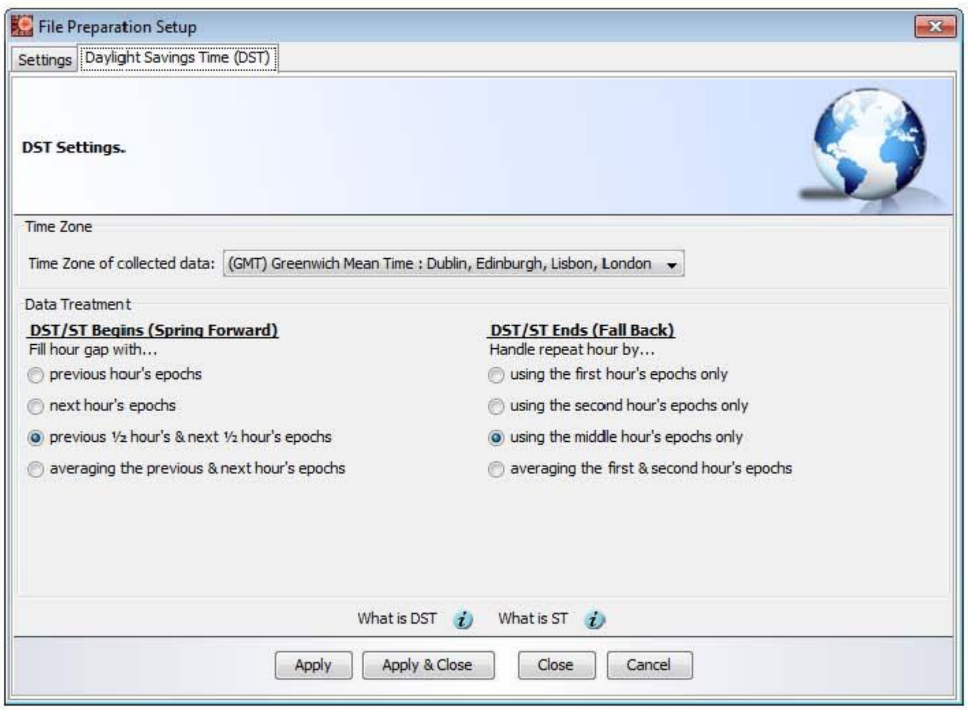


Figure . Daylight Savings Time (DST) configuration screen

15

The first step is to select the time zone where the data were collected. Then the user must choose how they would like to fill the hour gap (in the spring) or handle the repeated hour (in the fall). More specific information on these two sets of options is available by selecting the question mark (i) links which describe in detail What is DST (APPENDIX E) and What is ST (APPENDIX F).

Note: Once you have chosen you options be sure to use the apply button or apply and close to save your selections.

2.2 File Prep. button

The File Prep. Button pop-up houses 4 separate tabs that all deal with different data manipulation options (Figure 20): i) Back Fill; ii) Forward Fill; iii) Replace Data; iv) Data Modeling.

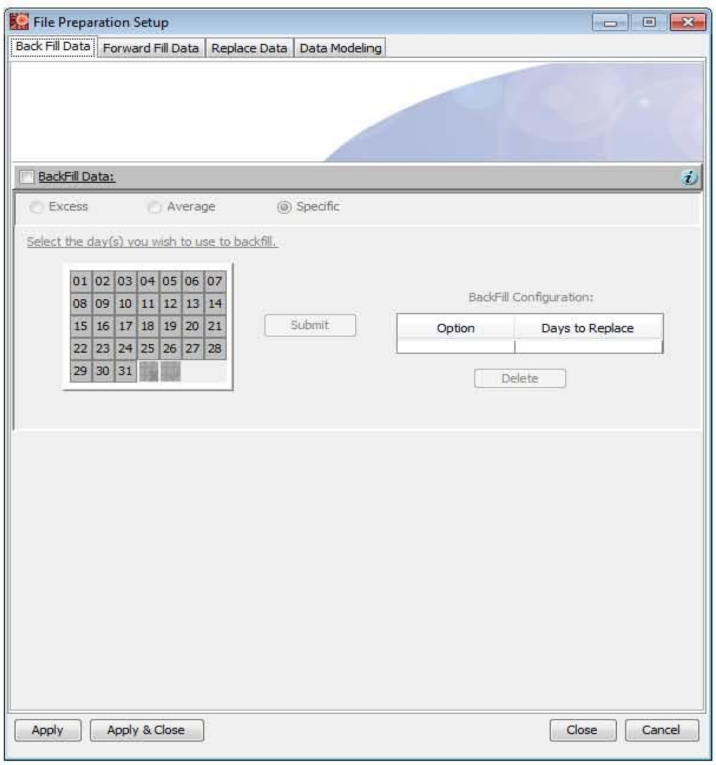


Figure . File Prep. button pop-up screen

Each tab contains a pop-up help window (click the more information link) that further explains each function. It is advisable to use as little data manipulation as possible when analyzing your data. If manipulations are necessary, be sure that they can be theoretically or practically justified. Watch out for things like non-response bias or potential mismatches in temporality caused by data manipulations.

Note: These functions are for advanced users and advice should be sought on their proper use. Also, many of the data manipulation functionalities require the user's data to be in fixed day of the week sequences in order to allow for batch capabilities. As a result, it may require that the user run separate batches if the deployment strategy for some files differs.

2.3 Runtime Settings button

The Runtime Settings button pop-up screen (Figure 21) allows the user to choose how they wish to deal with strings of consecutive epochs of zero counts. This simple algorithm allows users to label continuous strings of zeros that are biologically implausible as non-wear so as to not dilute key outcome variables such as average counts per minute.

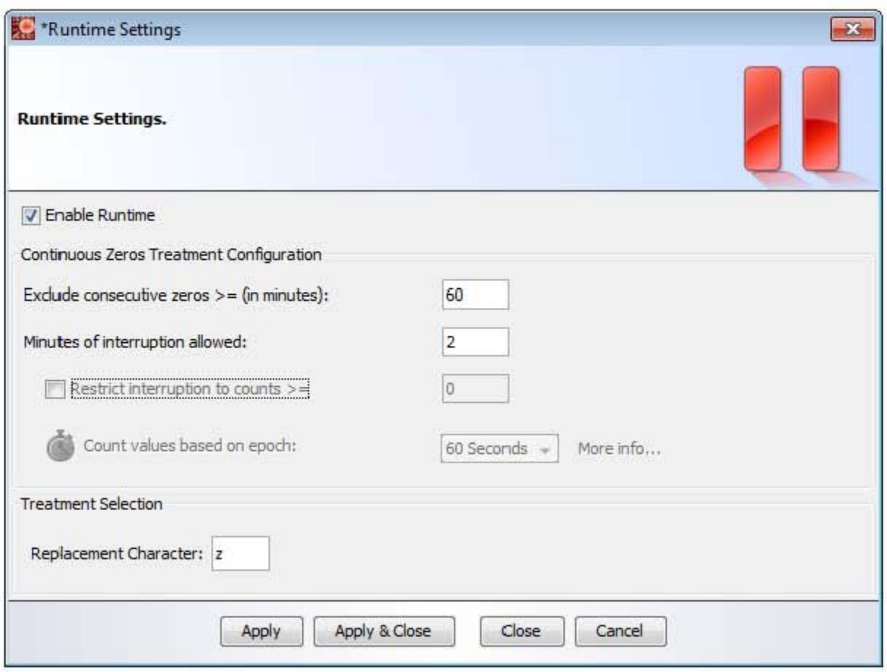


Figure . Runtime Settings configuration screen

The first input box is the duration that signifies the upper limit on what constitutes a period of zeros that are too long to be considered plausible. The second input allows for instances of interruptions in the continuous zero strings. This option also has a count level option that can be selected to further indicate what is an allowable interruption. Under the treatment selection the user can choose how they would like to code the continuous zeros. Figure 21 indicates the preferred options for many users.

Note: At the bottom of this, and many other functions, there is an input labeled Base Epoch. This is where the user specifies that the selections they made above are relevant only for epochs of the chosen duration. This allows KineSoft to 'scale' these settings should the user load a file with a different (i.e., longer or shorter) epoch.

2.4 QAQC Configuration button

This feature (Figure 22) allows the user to choose:

i) how many hours/minutes of wear time will be required to constitute a valid day of wear

ii) how many days (and if desired, the type of day) that constitutes a valid file

iii) QAQC specific inputs related to spurious data (plateau trigger and value and a spurious threshold input).

Please be aware that the QAQC feature is largely a visual tool to assist the user in the near real-time determination of the quality of their data. The visual feedback is displayed in the Pre-Processed pane of the KineSoft Process Center. Please also note that KineSoft only excludes invalid days when calculating totals and per values, the user will still receive full information on the other outcome variables for invalid days. Lastly, please be aware that the spurious data threshold and the plateau trigger were included in the KineSoft QAQC module because they have proven effective in terms of their ability to single out potentially erroneous data. However, please be aware that KineSoft does not remove these potentially questionable data, it merely functions to pinpoint them to the user so that they may best decide how to handle them. For example, data found to be above the spurious threshold are not deleted or removed, they are simply identified via a log for the user to deal with how they see fit.

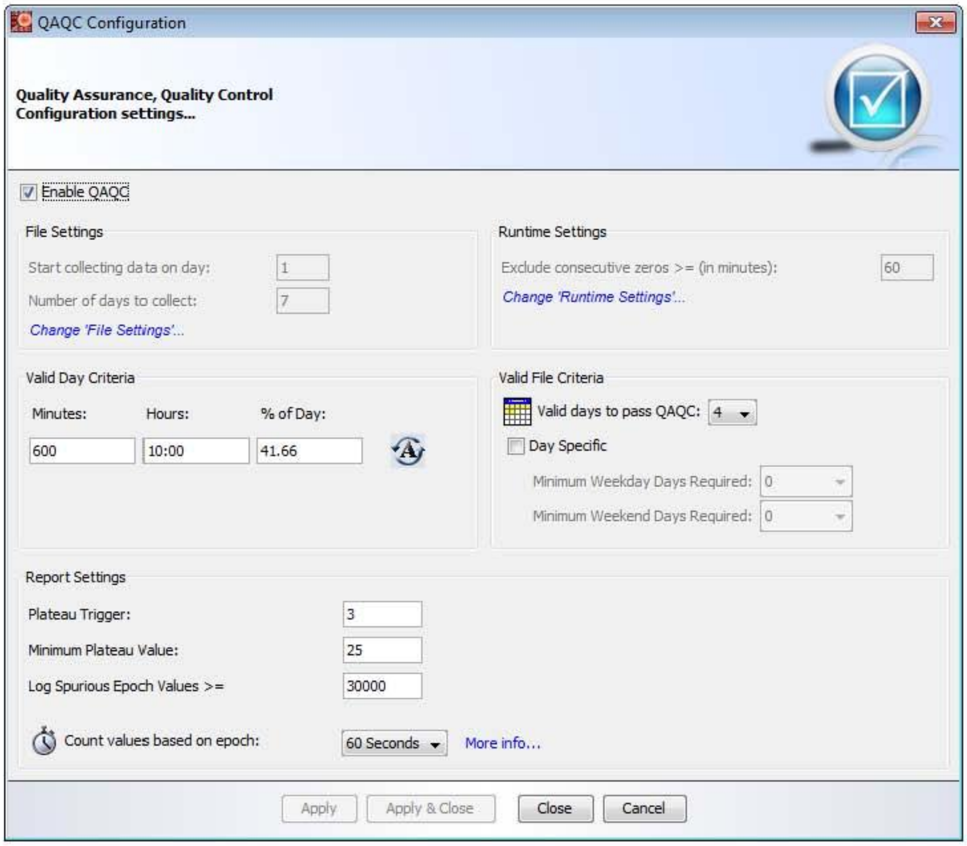


Figure . QAQC configuration screen

Note: At the bottom of this, and many other functions, there is an input labelled Base Epoch. This is where the user specifies that the selections they made above are relevant only for epochs of the chosen duration. This allows KineSoft to 'scale' these settings should the user load a file with a different (i.e., longer or shorter) epoch.

2.5 Cutpoints button

Selecting the Cutpoints button opens up an input table pop-up screen (Figure 23). This feature allows the user to choose which intensity thresholds are required. Users can create, save, rename, and delete simple counts based cutpoints or more complex regression equation based cutpoints based on METs or other variables such as age and/or weight.

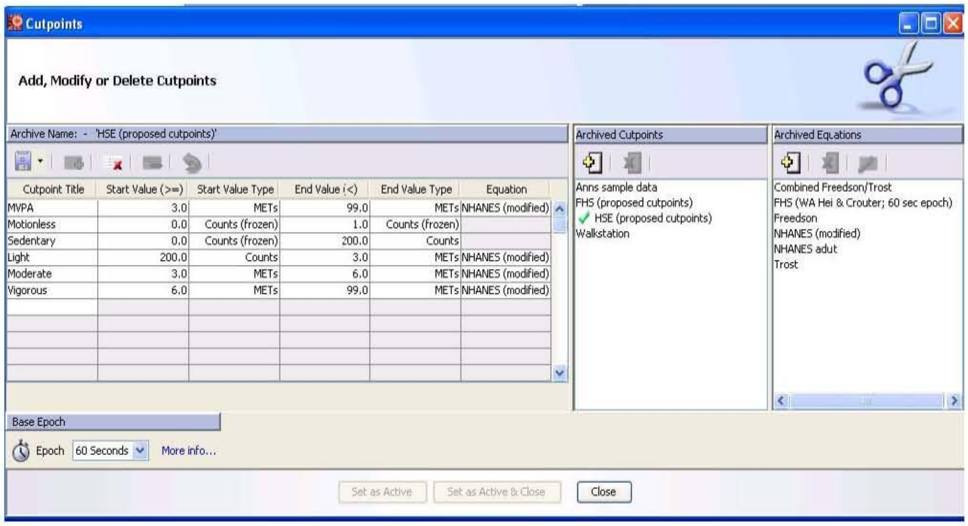


Figure . Cutpoints archives

The user can create and save their own cutpoints or use pre-loaded ones. Cutpoints can be created with either count or METs based anchors. For ease of understanding it is advisable to present the variables in some logical order. For example in Figure 23, the most important outcome variable was placed in row one because it will then be the first variable cluster in the report. Then, the remaining cutpoints appear in intensity order.

The cutpoints window has a further function that allows users to create custom equations which can be useful for more complex cutpoints such as the age-specific cutpoints developed by Freedson as published by Trost et al. 2002 (Figure 24).

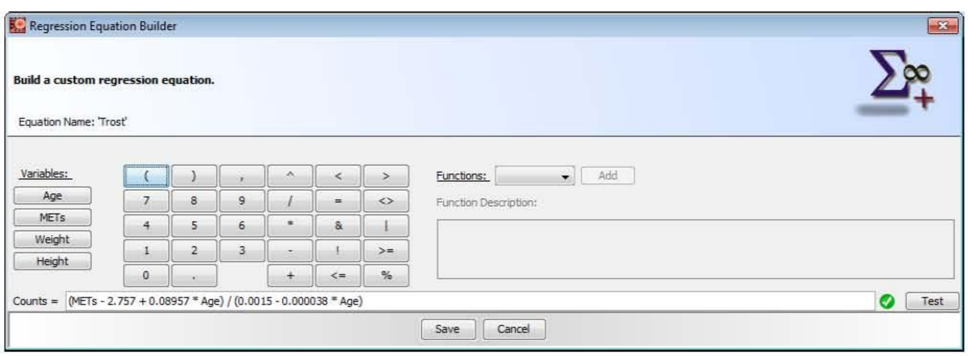


Figure . Regression Equation Builder

The regression equation builder is a powerful tool that allows the user to evolve their cutpoint archive to keep pace with any published equations. The equation builder also has a built in equation checker to help ensure your mathematical expression is valid. If it is invalid the green check mark in Figure 24 will be replaced by a red 'x'. Once your regression equation is validated mathematically, it is wise to then use the Test button to check to ensure it is performing as you expect it to (Figure 25). For example, by inputting age=12 and METs=3, one can see that the resulting count cutpoint is being calculated correctly (as it matches (rounding differences aside) the thresholds as published). Please note that like all inputs, the full cutpoints archive chosen by the user will be recorded in the Vitals tab of the report.

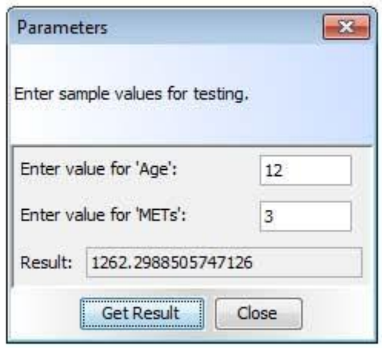


Figure . Regression Equation Tester

Note: At the bottom of this, and many other functions, there is an input labelled Base Epoch. This is where the user specifies that the selections they made above are relevant only for epochs of the chosen duration. This allows KineSoft to 'scale' these settings should the user load a file with a different (i.e., longer or shorter) epoch.

2.6 Fractions button

When the user selects the Fractions button a pop-up screen (Figure 26) similar to the cutpoints archive is opened. This screen allows the user to decide how they want to fractionalize the various intensities of physical activity. For example, for many PA guidelines, the MVPA must be accumulated in bouts of 10 or more minutes (so in the above example, sporadic MVPA would not count towards these guidelines). This tool also has the ability to allow exceptions in the accumulation of bouts. However, please note that the exceptions are listed in time not number of epochs. Also note that the exceptions can be either consecutive or non-consecutive in the bout string. Finally, similar to the cutpoints archive, the Fractions can be created, renamed, saved, and deleted.

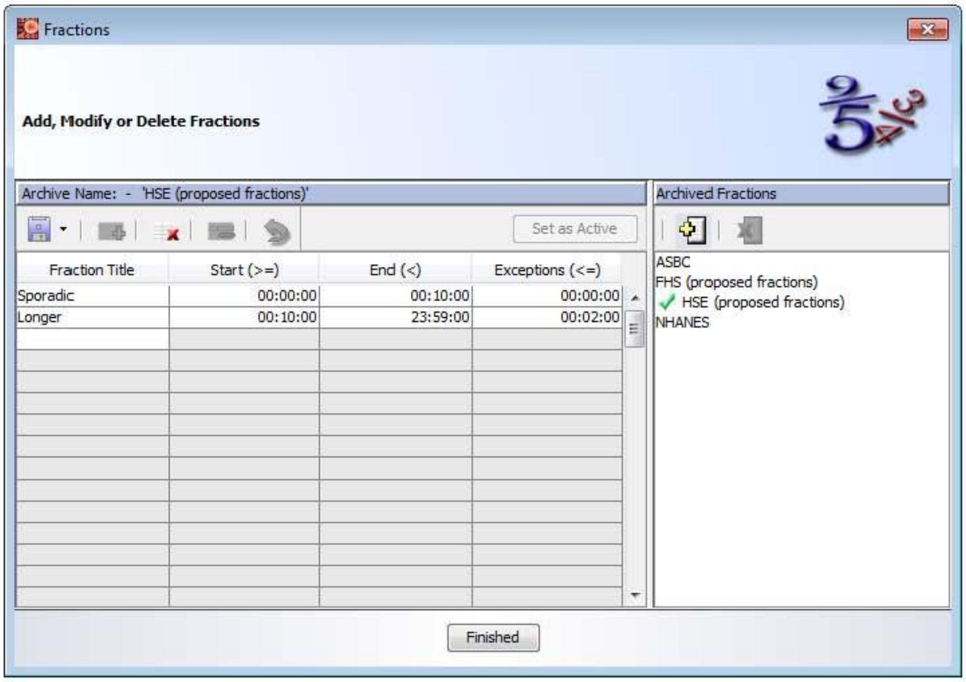


Figure . Fractions archive

2.7 Windows button

When the user selects the Windows button a pop-up screen (Figure 27) similar to the Fractions archive is opened. This screen allows the user to decide how they want to summarize all the outcome variables (e.g., wear, non-wear, all intensities, all fractions) into time blocks of their choice. In Figure 27, we simply divided the day up into 4 x 6 hour blocks. Other examples could include putting in times for recess or lunch, am or pm commute, a specific gym session etc. (Figure 28).

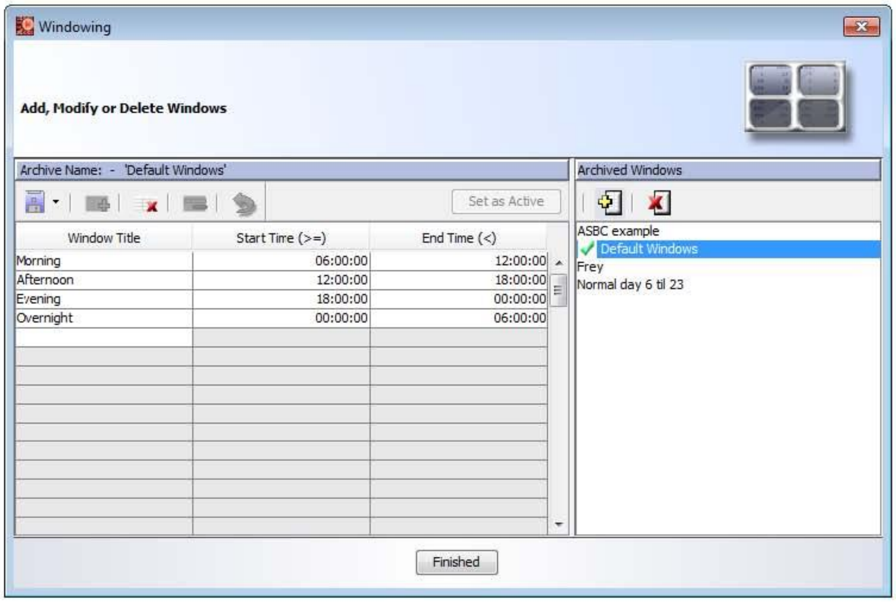


Figure . Windowing configuration screen

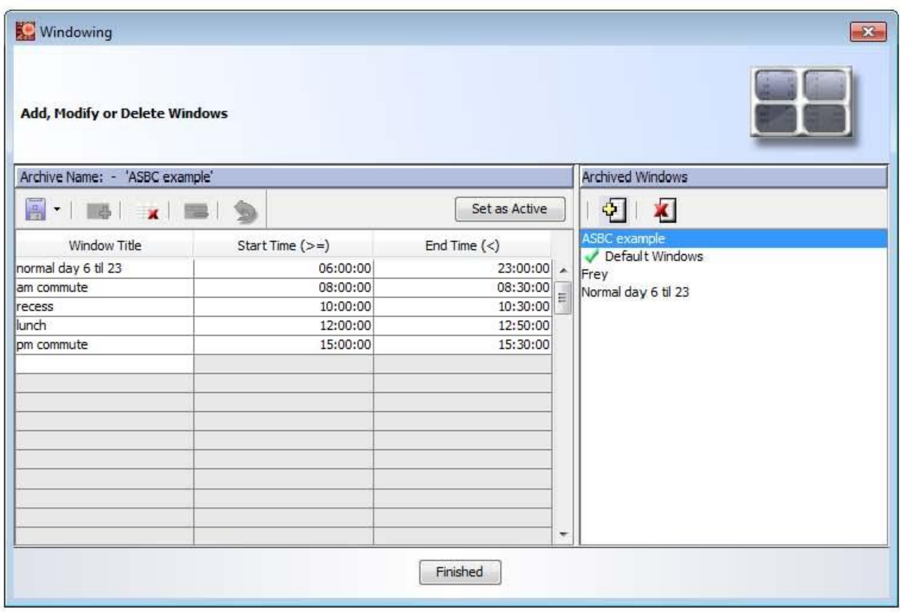


Figure . Another example of windowing configuration

3.0 Pre-Processing and Post-Processing Panes

Once a user has gone through and done an initial selection of the analytical inputs using the 7 red buttons along the left of the Process Center, they are ready to load data files into the Pre-Processing area on the leftward pane of Process Center (Figure 29).

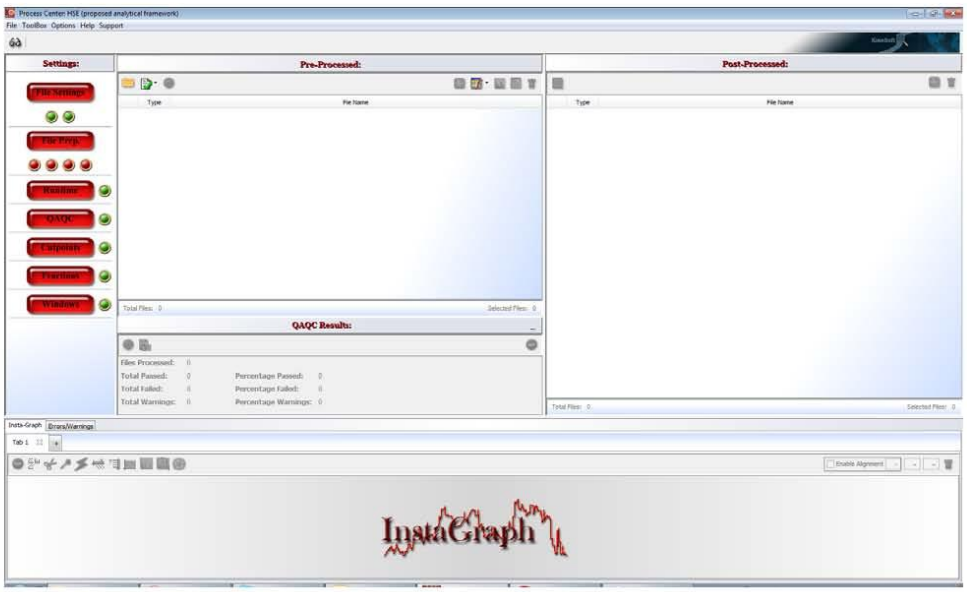


Figure . Pre-Processed pane

To do this they can either choose the Select Files option from the File drop-done menu, or more simply, click on the manila file folder at the top left of the Pre-Processed pane. This will open the typical Windows based file browser allowing you to load into KineSoft 1 or more files. Note: When loading large batches (i.e., more than 500 or 1000 files), the pre-processing time can be significant, especially if the computer is of low spec. Once the files are loaded (Figure 30) much of the front end visual feedback is readily available to the user. For example the first thing to notice is that KineSoft automatically recognizes the type of accelerometer file that is being run as indicated by the icon next to the file name (e.g., Actigraph, Actical, RT3, BioTrainer Pro, etc.). You will also notice that KineSoft provides a QAQC summary at the bottom of the Pre-Processed pane stating that of the 30 files loaded, 20 passed the valid file criteria whereas 10 failed and the percentages are also provided. We can also easily tell which files pass as they are indicated by a Q with a green check while those that failed are marked with a Q with a red x. At any time if we want further information on a given file we need only hover the mouse over the information (i) icon (Figure 31). The hover information provides quick access to key header info, start and stop date and time info, setup info, and then a day by day indication of wear time and validity status.

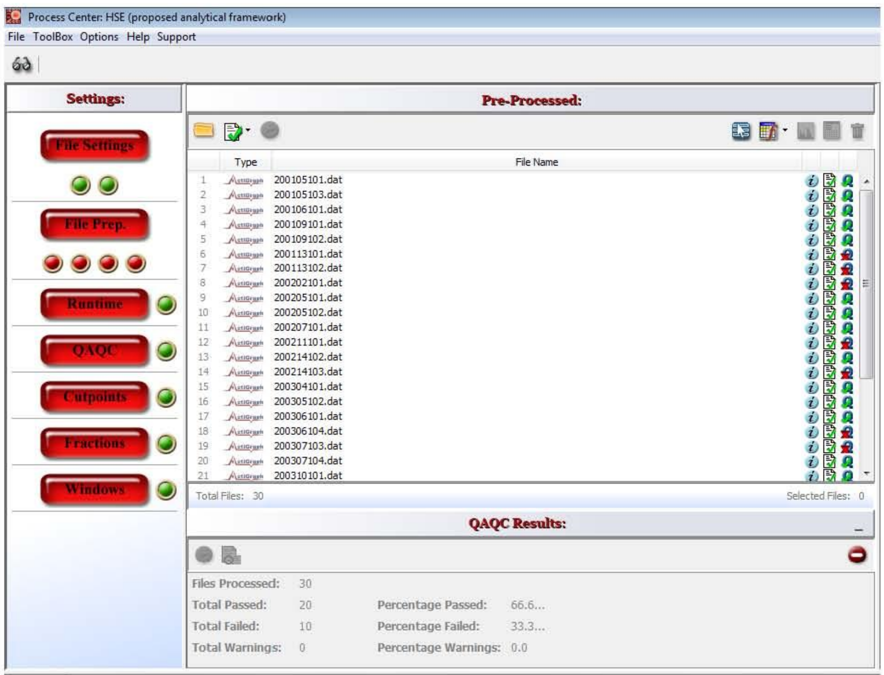
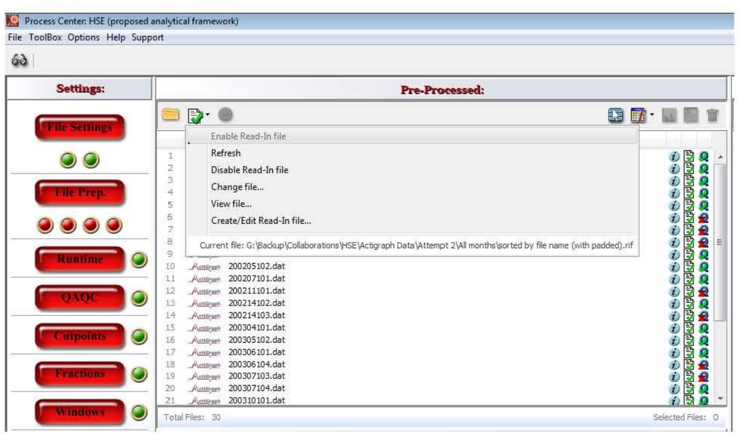


Figure . Files loaded into the Pre-Processed pane

Next to the manila file folder is the

Figure . Hover information screen for a given file

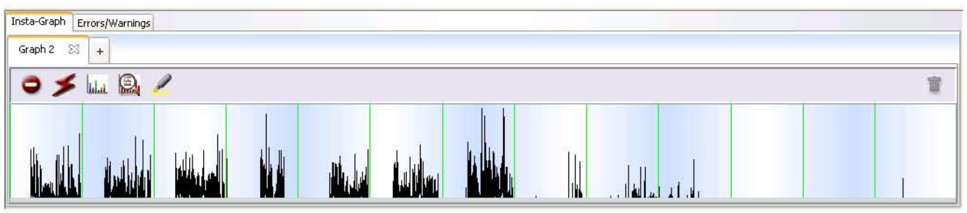


26

In addition to these red buttons on the left aspect of the user interface, there is also a comprehensive graphing utility called the InstaGraph located at the bottom of the Process Center (Figure 29).

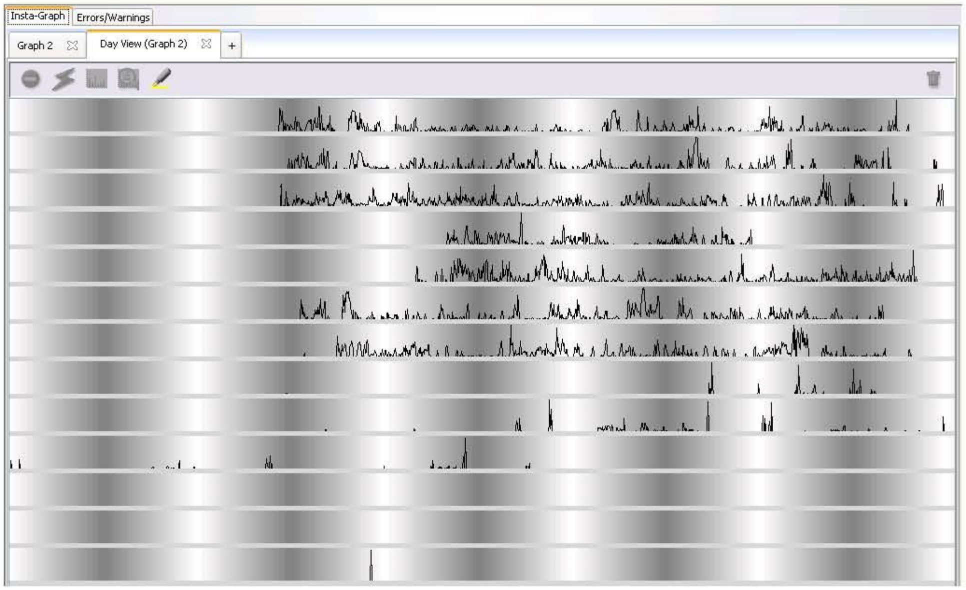
Figure . Instagraph file visualization tool

By dragging and dropping a file from the Pre-Processed hemisphere or using the graphing icon or by right clicking, the user can instantly visualize the day by day trace of a given data file:



Increased functionality can be gained by adding vertical line markers and desired times such as those in the above image at 0000 hrs daily.

27



Further functionality can be gained by zooming into the day by day data in a vertical stack so that the daily temporality is highlighted as in the above image.

In fact, there are many more InstaGraph features that provide a host of applications for users.

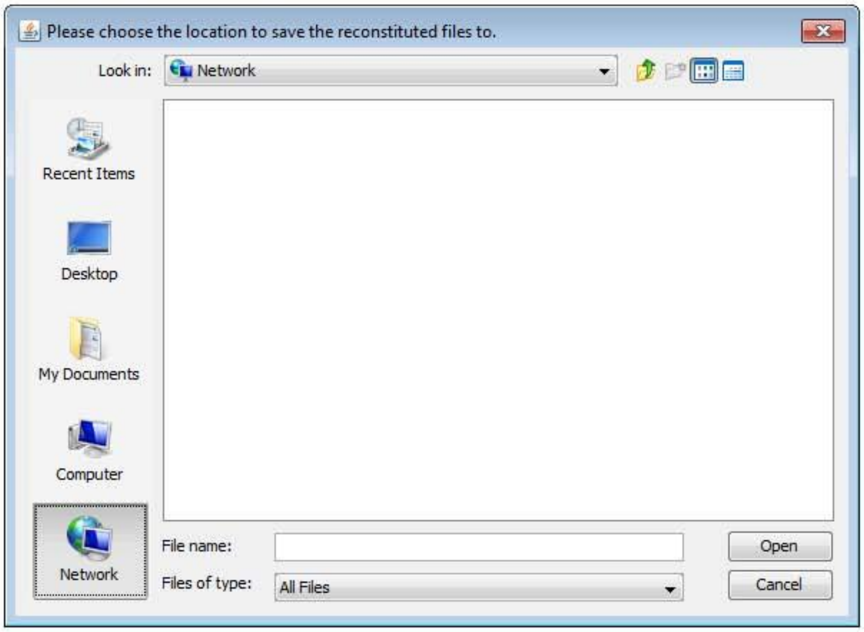
28

APPENDICES

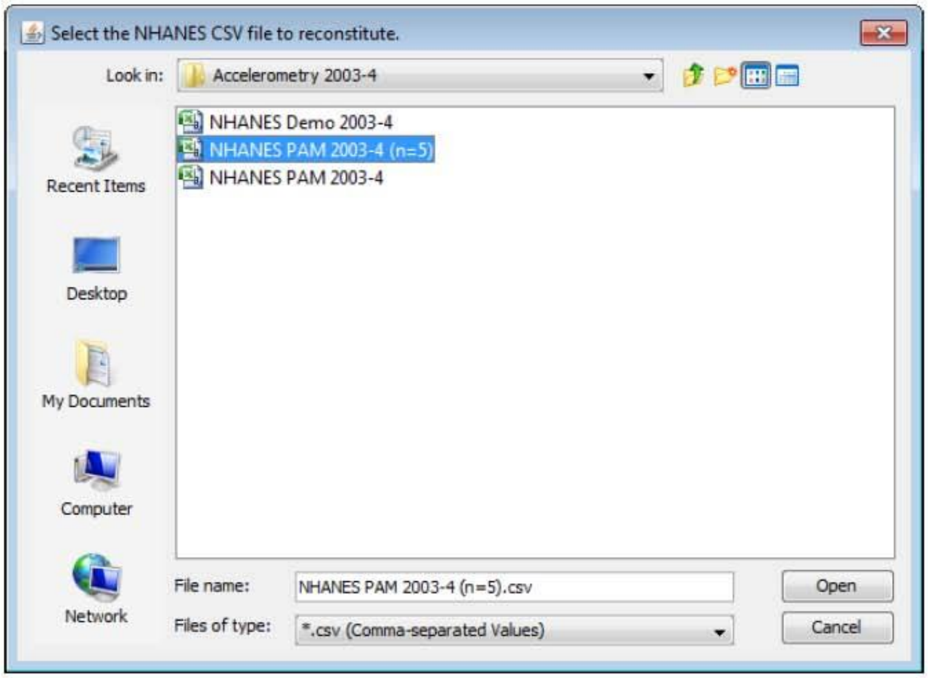
APPENDIX A – NHANES Reconstitutor

NHANES Reconstitutor- allows the user to open up a very simple self contained piece of software that will read in raw NHANES data downloaded in .csv format from the NCHS website and will reconstitute raw .dat files complete with header so they can be analyzed using KineSoft.

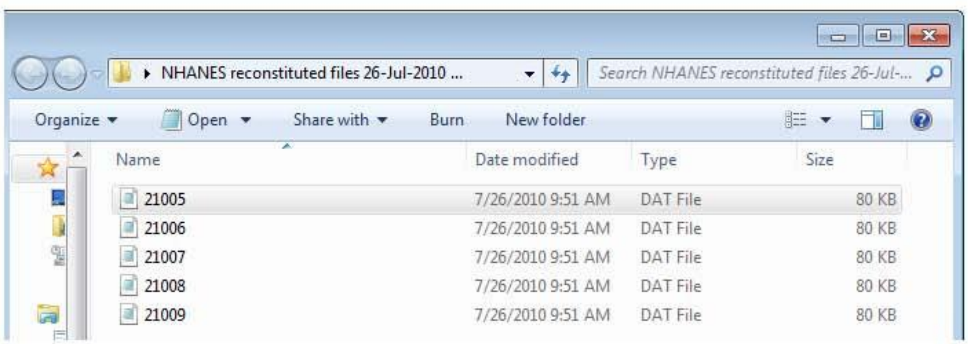
The first step is outlined at the top of the first pop-up window:



The second step is outlined at the top of the second pop-up window:



Once you have chosen the .csv file to reconstitute, click the Open button and a file folder will be created in your desired location with the newly created .dat files (see below for example).



Of course, because no data from the original header are available, the program creates fictitious data (see below for example).

31

21009 - Notepad

File Edit Format View Help

```
|----------- Data File Created By KineSoft File Reconstitution Program in Actigraph Format -----------
Serial Number: 999999
Start Time 00:00:00
Start Date 01/04/2004
Epoch Period (hh:mm:ss) 00:01:00
Download Time 00:00:00
Download Date 01/11/2004
Current Memory Address: 10080
Current Battery Voltage: 1.00     Mode = 0
--------------------------------------------------
0       0      0      0      0      0      0      0      0      0      0      0      0
0       0      0      0      0      0      0      0      0      0      0      0      0
0       0      0      0      0      0      0      0      0      0      0      0      0
7       0      2      7      0     14     29      0      0      0      0      0      0
7    2385   1368    630   2623   1714    399   1136   2577   1541    981    680   1806      5
0    1443      3      0      0      0      0      0      0      0      0      0      0
0       0      0     19     12     14     17    298   1257    548   1159    429    972      3
0     566      9     11      7      5    200    316     58      3    407      6     11      5
9     105    159     25     62    208    254    159    133    271    254    329    241      1
4     468    802    858    405    532    508    306     79     16     47     31     44
0       0      0      0      0      0      0      0      0      0      0      0      0
0       0      0      0      0      0      0      0      0      0      0      0      0
0       0      0      0      0      0      0      0      0      0      0      0      0
0       0      0      0      0      0      0      0      0      0      0      0      0
7     287     10   1659    654    189      0      0      0      0    776   1212   1313      1
5    1554   1423   1589   1832   1381   1892   2085   1681   2741   2834   3120   4223     23
5    1436   2365   5556   1892   5223   3492   1095   1606   1657    190   1130   1258      5
0       0      0      0      0      0      0   1143    659     67    117     11    119     18
0       0    225     82    784    520   2898    870    889    592    449    622    671      8
4      26     75     65      5      0      0      6      0      0      0   1185      0
9      41     27     33      0    279   1343      0      1     11      5      0      0
5       1      0      0      0      0      2    188    698    129    146      0    283
0       0      0      0      0      0      0      0      0      0      0      0      0
0       0      0      0      0      0      0      0      0      0      0      0      0
0       0      0      0      0      0      0      0      0      0      0      0      0
0       0      0   2242    215    228      1    501    907    836    250   1036   1243
9     250    167     88     14      3    342   2131    692    527   1183   1568    117      6
```

For NHANES data from 2003-04, the reconstituted .dat files will be dated with the year 2004. For NHANES data from 2005-06, the reconstituted .dat files will be dated with the year 2006. In both cases, the correct day of the week will be retained by offsetting the Start Date from January first by 1-7 days. This will result in a Download Date which is 7 days later.

Note: i) serial number is arbitrarily set at 999999; ii) all start times are 00:00:00 as per NHANES deployment methods; iii) all Epoch Periods are 1 minute as per NHANES methods; iv) Current Battery Voltage is arbitrarily set at 1.00; iv) the first line of the header highlights the fact that the header data was generated by KineSoft.

APPENDIX B – KineSoft System Requirements

	KineSoft System Requirements	Minimum	Recommended	Notes
	Free Memory (RAM)	1 GB	2 GB or greater	1
Hardware	**Free Hard Drive Space**	20 MB	30 MB	2
	Screen Resolution (width x height)	1024 x 768	higher	3, 4
	Operating System	Windows XP	Windows 7	5
	Java Runtime Environment (freeware)	JRE 1.6	JRE 1.6 or higher	6, 7
	Microsoft Excel	'97 or higher	2007	8
Software	**FileZilla (freeware)**	not necessary	facilitates the initial installation of KineSoft	9
	Active Internet Connection	not necessary	required to receive KineSoft auto updates	10
	Skype (freeware)	not necessary	useful for providing online KineSoft support	11
Accessories	**Mic & speakers or headset (earphones & mic)**	not necessary	allows voice communication for online KineSoft support	12

Notes

1	**As long as KineSoft has 1 GB or more free RAM available, the speed the files are pre- and post-processed and reports generated is dependent on the processor speed**	
2	**KineSoft is a compact program so it takes up a negligible amount of storage space on your C: drive**	
3	**The larger the screen the easier it is to see and access the user interface and the graphing functions**	
4	**You can check what your screen resolution is using this link**	http://www.whatismyscreenresolution.com/
5	**Vista is also supported**	
6	**You can download the JRE for free at the following link**	http://www.java.com/en/download/index.jsp
7	**You can check what version of JRE you have at the following link**	http://www.javatester.org/version.html
8	**Excel 2007 allows large batch reports to remain in one worksheet as it has many more rows and columns than previous versions**	
9	**You can download FileZilla for free at the following link**	http://filezilla-project.org/download.php
10	**An active internet connection will automatically check for KineSoft updates each time the program is opened**	
11	**You can download Skype for free at the following link**	http://www.skype.com/intl/en-gb/download/skype/windows/
12	**We tend to use Skype and another online meeting software called GoTo Meeting quite often and both require a mic and speakers**	

APPENDIX C – Installation Instructions for KineSoft Software

Version 1.02 (02-24-2010)

Thank you for your interest in KineSoft software, the following guide will walk you through installing the software onto your computer. KineSoft is available on the following Operating Systems:

- Windows XP
- Windows Vista
- Windows 7
- Mac OS X (10.5 +)

Installation:

1. First you need to obtain a copy of the KineSoft installation file. The most recent installation file can be downloaded from our FTP server @ emf.selfip.com using port 21002. Please refer to the 'FTP Client Setup' section below for help obtaining this file using an FTP client.

2. Once you have the installation file (ex: KineSoft Gen3_v3.3.21.msi) downloaded to your computer, you can simply double click the file to start the installation process. You should be greeted with the following screen:

Follow the setup wizard through its various steps until the installation is complete. Once completed you should see the KineSoft icon located on your desktop. 

3. KineSoft should now be installed on your machine and ready for use. Double clicking the KineSoft icon will launch the program for the first time. Be patient as the program sets up the database and creates the necessary connections.

4. If this is the first time KineSoft has been installed on this computer you may be greeted with a License request screen. KineSoft is licensed per machine and as such needs a valid license to open. Please fill out the license request form and click "Request License". An email will be sent to kinesoft.licensing@gmail.com for approval and creation. Once you receive a license file you can start using KineSoft, which will allow you to move on to step #5.

Note: If the computer KineSoft is being installed on does not have an active internet connection, or SMTP outbound traffic is blocked by your firewall settings you will be prompted to email kinesoft.licensing@gmail.com directly. The prompt will look similar to the image below:

5. When KineSoft loads you will see a splash screen indicating the program is loading, you can see the current version in the lower right corner.

Current Version indicator

6. KineSoft should now be fully functional and ready for use.

36

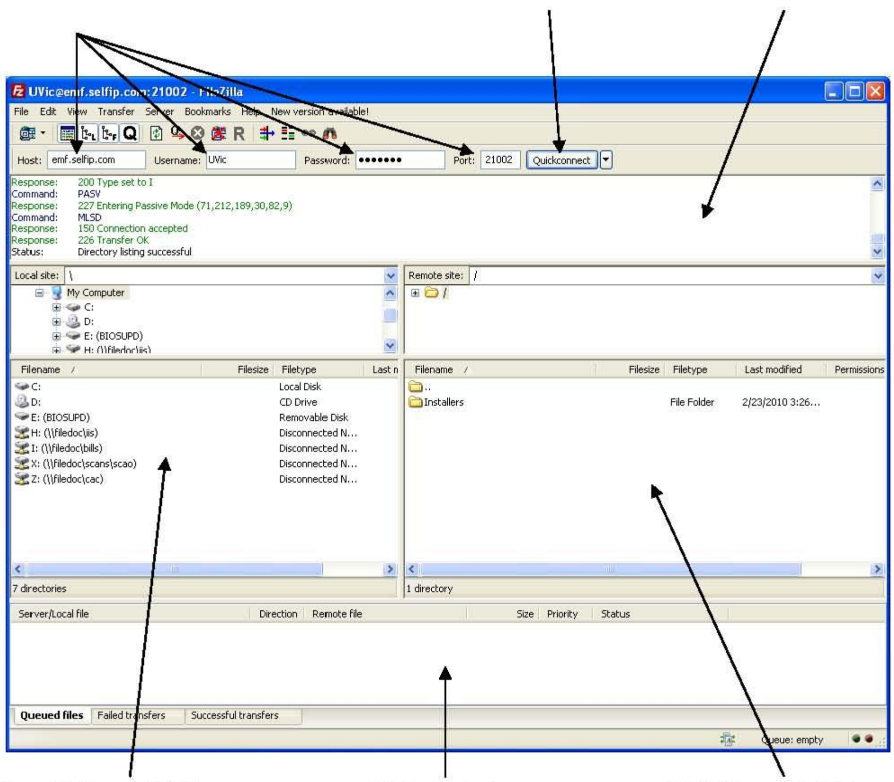
FTP Client Setup

First off, it is usually better to download large files through and FTP site using an FTP Client. Filezilla Client is a great free resource and can be found/downloaded at http://filezilla-project.org/download.php. Using and FTP Client will help ensure that you receive the full download without errors or timeouts.

FTP Host: emf.selfip.com
Username: username
Password: ******* (case sensitive)**
Port: 21002

Enter above configuration in the appropriate areas on the screen, once completed click the "Quick Connect" button. You should see a "Directory listing successful" in the log section once a connection has been established.

Enter credentials here. **Connection button.** **Log area.**



Local files and folders. **Status window.** **FTP files and folders.**

To download a file from the FTP site to your local computer you can navigate to the file you want and simply drag the file to a location on your local computer. The file will begin to download and you can view the download progress in the bottom window.

APPENDIX D – **About the KineSoft Developers**

Name: Dale Esliger
Background: Research Associate, University of Saskatchewan and Honorary Research Fellow, University of Exeter
Expertise: Physical Activity Measurement
Email: dale.esliger@usask.ca
Skype Name: Dale Esliger
Hometown: Rothesay, NB, Canada
Present Location: Saskatoon, SK, CAN

Name: Eric Finley
Background: Java Programmer II, State of Colorado Judicial Dept.

Expertise: Software development in Java based applications; data mining
Email: kinesoft.support@gmail.com
Skype Name: Eric Finley
Hometown: Rothesay, NB, Canada
Present Location: Denver, CO, USA

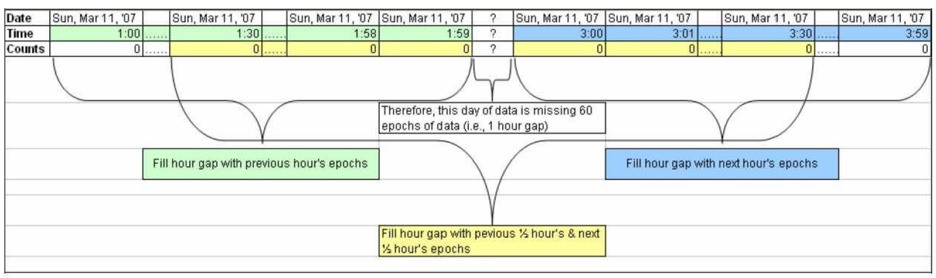
For software bugs and technical related enquires contact Eric; in case of content, outcome variables, input parameters etc. contact Dale.

APPENDIX E – Daylight Saving Time (DST) [North America]

Historically, DST has always started on the first Sunday in April and ended on the last Sunday in October; however, beginning in 2007, DST will begin on the second Sunday in March and end the first Sunday in November.

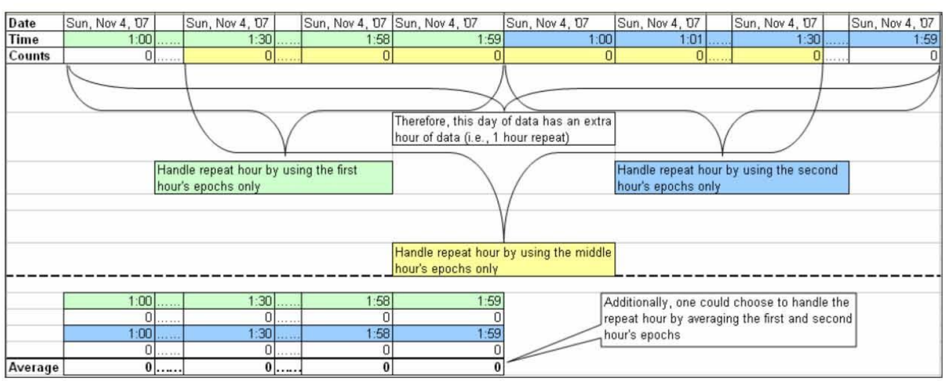
In order to save daylight in the spring, clocks are set ahead by 1 hour (i.e., spring forward) on the above-mentioned dates. This "re-setting of the clocks" occurs at 2AM local time in participating locations (not all locations participate (e.g., most of Saskatchewan opts out of DST)). The schematic below describes how this process might affect chronologically anchored data during DST.

Actigraph accelerometer data collected on March 11, 2007 at 1 minute epochs:



In fall of the year, DST ends and the clocks are set back by 1 hour (i.e., fall back) on the above-mentioned dates. This "re-setting" of the clocks occurs at 2AM local time (again, not all locations participate in DST). The schematic below describes how this process might affect chronologically anchored data when DST ends.

Actigraph accelerometer data collected on November 4, 2007 at 1 minute epochs:



Time change dates for the years 2000-2025.

DST Begins	DST Ends
Apr 02 2000	Oct 29 2000
Apr 01 2001	Oct 28 2001
Apr 07 2002	Oct 27 2002
Apr 06 2003	Oct 26 2003
Apr 04 2004	Oct 31 2004
Apr 03 2005	Oct 30 2005
Apr 02 2006	Oct 29 2006
Mar 11 2007	Nov 04 2007
Mar 09 2008	Nov 02 2008
Mar 08 2009	Nov 01 2009
Mar 14 2010	Nov 07 2010
Mar 13 2011	Nov 06 2011
Mar 11 2012	Nov 04 2012
Mar 10 2013	Nov 10 2013
Mar 09 2014	Nov 09 2014
Mar 08 2015	Nov 08 2015
Mar 13 2016	Nov 13 2016
Mar 12 2017	Nov 12 2017
Mar 11 2018	Nov 11 2018
Mar 10 2019	Nov 10 2019
Mar 08 2020	Nov 08 2020
Mar 14 2021	Nov 14 2021
Mar 13 2022	Nov 13 2022
Mar 12 2023	Nov 12 2023
Mar 10 2024	Nov 10 2024
Mar 09 2025	Nov 09 2025

Note: All dates fall on a Sunday

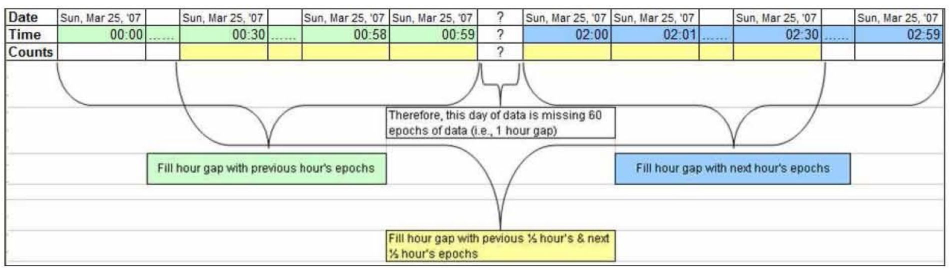
41

APPENDIX F – Summer Time (ST) [European Union]

ST begins on the last Sunday in March and ends on the last Sunday in October. To date, no plans have been made to change this format to align with the recent changes in North America.

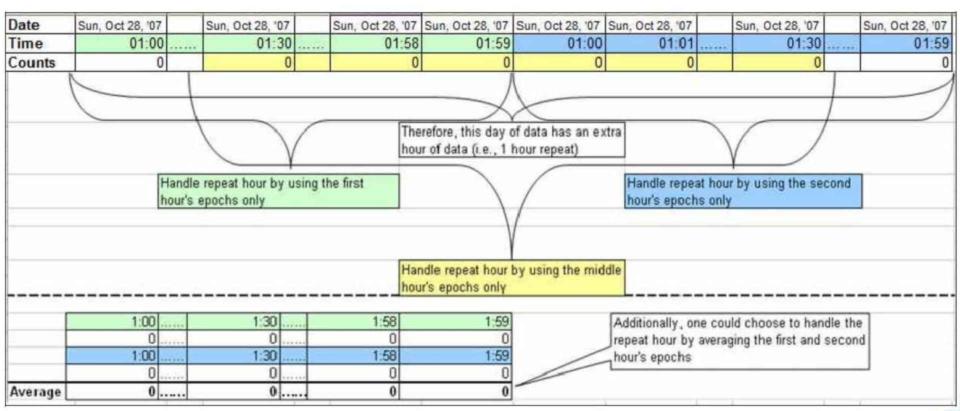
In order to save daylight in the spring, clocks are set ahead by 1 hour (i.e., spring forward) on the above-mentioned dates. This "re-setting of the clocks" occurs at 1AM Universal Time (i.e., unlike DST in NA, ST in the EU occurs at the same time in all locations) in participating locations (not all locations participate). The schematic below describes how this process might affect chronologically anchored data during ST.

Actigraph accelerometer data collected on March 25, 2007 at 1 minute epochs:



In fall of the year, ST ends and the clocks are set back by 1 hour (i.e., fall back) on the above-mentioned dates. This "re-setting" of the clocks occurs at 1AM GMT. Please note that the activity monitor data will be affected at local time; for example, in Portugal, ST ends at 2AM local time. The schematic below describes how this process might affect chronologically anchored data when ST ends.

Actigraph accelerometer data collected on October 28, 2007 at 1 minute epochs (in the WEST time zone of the EU):



Time change dates for the years 2000-2025.

ST Begins	ST Ends
Mar 26 2000	Oct 29 2000
Mar 25 2001	Oct 28 2001
Mar 31 2002	Oct 27 2002
Mar 30 2003	Oct 26 2003
Mar 28 2004	Oct 31 2004
Mar 27 2005	Oct 30 2005
Mar 26 2006	Oct 29 2006
Mar 25 2007	Oct 28 2007
Mar 30 2008	Oct 26 2008
Mar 29 2009	Oct 25 2009
Mar 28 2010	Oct 31 2010
Mar 27 2011	Oct 30 2011
Mar 25 2012	Oct 28 2012
Mar 31 2013	Oct 27 2013
Mar 30 2014	Oct 26 2014
Mar 29 2015	Oct 25 2015
Mar 27 2016	Oct 30 2016
Mar 26 2017	Oct 29 2017
Mar 25 2018	Oct 28 2018
Mar 31 2019	Oct 27 2019
Mar 29 2020	Oct 25 2020
Mar 28 2021	Oct 31 2021
Mar 27 2022	Oct 30 2022
Mar 26 2023	Oct 29 2023
Mar 31 2024	Oct 27 2024
Mar 30 2025	Oct 26 2025

Note: All dates fall on a Sunday

43

APPENDIX E

Curriculum Vitae

CURRICULUM VITAE

Dale W. Esliger dale.esliger@usask.ca **306-966-1085**
College of Kinesiology, University of Saskatchewan 306-966-6464 fax

EDUCATION

University of Saskatchewan **Present**
PhD Candidate (ABD), College of Kinesiology
Dissertation: *Refining the accelerometric profiling of physical activity*

University of New Brunswick **2002**
M.Sc. Exercise and Sport Science, Faculty of Kinesiology
Distinction: First Division (cumulative GPA 3.8/4.3)
Thesis: *Neuromechanics of maximal effort squat jumps*

University of New Brunswick **2001**
Diploma of University Teaching

University of New Brunswick **2000**
B.Kin. Exercise Science, Faculty of Kinesiology
Distinction: First Division (cumulative GPA 3.9/4.3)

RESEARCH POSITIONS

Research Associate **2010 – Present**
College of Kinesiology, University of Saskatchewan

- The primary aim of this research position is to facilitate the completion of a scholarly journal supplement to communicate the results of a 2 million dollar community-wide physical activity intervention. As a secondary role, this position provides research and management support for the development of a new childhood obesity program.
- Other duties relate to campus-wide research consulting and mentorship of faculty and graduate students in the area of physical activity epidemiology and measurement.

Scientific Collaborator **2008 - Present**
The Framingham Heart Study / Boston University School of Medicine

- The Framingham Heart Study is an observational study to find relationships between risk factors, genetics, heart and blood vessel disease, and other health conditions over three generations. With funding from the National Heart Lung and Blood Institute, collecting accelerometric measures of physical activity are being collected on over 5000 adults as part of the second examination cycle of the Third Generation Cohort. My role is to provide content expertise in physical activity measurement to facilitate the acquisition of data of the highest quality that will enable generations of researchers world-wide to analyze these data to address scientific questions of great contemporary relevance.

Scientific Collaborator **2008 - 2010**
The Health Survey for England / National Centre for Social Research

In addition to general health, the Health Survey for England assesses specific areas of health, like heart disease or asthma, and investigates specific population groups, such as mothers and children. The results are used widely, to estimate the proportion of the population with specific health conditions, to look at the commonly occurring factors that are associated with these health conditions, and to monitor targets in the government's health strategy. The 2008 HSE is committed to collecting and analyzing accelerometric measures of physical activity on over 3400 adults and 1400 children. My role is to provide content expertise in physical activity measurement, specifically related to data analyses and the production of government reports and peer reviewed publications.

Research Fellow **2007 - 2009**
School of Sport and Health Sciences, University of Exeter

- This industry funded research fellowship was sponsored by Unilever Corporate Research. The aim of the research was to assist in the development and testing of a novel accelerometer for the measurement of physical activity. The program of research included both laboratory- and field-based studies.
- This research also required a significant contribution to the management and administration of the research project, including resource management (personnel/budgets) and project management.
- In this role, I also contributed to the teaching and learning programs in the School and helped mentor undergraduate and postgraduate research students..

RESEARCH CONSULTING AND WORK EXPERIENCE

Founder and Chief Executive Officer **2006 – Present**
KineSoft

- KineSoft is a small privately held analytic and data visualization software company specializing in data mining applications related to accelerometric sensors.
- The software was initially designed over the course of my early graduate research and evolved from 2001-2005. In 2006 a dedicated professional programmer was hired and the company was formally launched to fill a gap in the market.
- As of February 16, 2011 the company has clients in over 20 universities and government laboratories in five countries (Canada, USA, England, Portugal, Spain).
- All code is produced and maintained by company-paid programmers; therefore, the company owns all intellectual property and controls all copyrights.
- As CEO, my role is to manage the innovation cycles for the software development as well as being responsible for physical activity measurement related expertise.

Foresight Consultant **2008**
The Technology Partnership plc, Cambridge, England

- The Technology Partnership plc is a leading independent technology and product development company
- Met with company executives to counsel them on the 'state of the field' as it relates to non-visual motion tracking and accelerometry.
- A brief horizon scan (i.e., scoping report) was compiled and delivered.

Research Consultant **2007 - 2009**
Research Centre in Physical Activity and Leisure,
Faculty of Sport Sciences, University of Porto

- The aim of this consultancy was to bolster the groups data mining capacity in terms of profiling childhood physical activity. Particular emphasis was placed on determining when children are active / inactive (e.g., class time, PE, recess, lunch) and how they are active / inactive (e.g., differences in intensity and/or the accumulation of activity). After meeting with the research team, discussing their research goals, and evaluating their data, we initiated the process of designing and deploying a custom software program to provide the rich array of outcome variables necessary to meet the objectives of their projects

Research Consultant **2007 - 2008**
Manitoba Institute for Child Health, Department of Pediatrics, University of Manitoba

- The aims of the research team were: 1) to evaluate outcomes of a mandatory physical activity policy in schools on childhood obesity and 2) to determine the dose of physical activity associated with healthy weight gain in youth.
- My role is to provide content expertise in objective physical activity measurement from the initial grant writing stage right through to the design of the analytical plan. I initiated the process of designing and deploying a custom software program to provide the rich array of outcome variables necessary to meet the objectives of their project.

Research Consultant **2006 - 2008**
Physical Health Measures Division, Statistics Canada

- Statistics Canada recently initiated the Canadian Health Measures survey, which aims to collect direct health measures data on a nationally representative sample (N=5000) of Canadians. My role is to provide content expertise in objective physical activity measurement. To date 3 separate contract research agreements have been delivered that focused on accelerometric technology assessment (e.g., technical reliability and validity as well as quality control and quality assurance).

Research Consultant **2006 - 2007**
School of Human Kinetics, University of British Columbia

- The aim of the research team was to determine (using accelerometry) if schools undergoing a physical activity intervention are more active than controls and if so, when (e.g., class time,

PE, recess, lunch) and how (e.g., differences in intensity and/or the accumulation of activity) were they more active.
- After meeting with the research team, discussing their research goals, and evaluating their data, I initiated the process of designing and deploying a custom software program to provide the rich array of outcome variables necessary to meet the objectives of their project.

Research Consultant **2006**
School of Physical Education, University of Victoria

- The aim of the research team was to profile (via accelerometry) the physical activity behaviour of pre-school children being cared for in home care environments in an effort to understand what helps predict an active vs. inactive environment.
- After meeting with the research team, discussing their research goals, and evaluating their data I designed and delivered a custom software program (complete with procedural documentation and training) to enrich the data analysis portion of their work.

Logistical Consultant **2004 - 2005**
Canadian Health Measures Survey (CHMS)
Physical Health Measures Division, Statistics Canada

- Planned, designed, implemented and evaluated alternative logistical options for the collection of various physical measures (e.g., anthropometrics, activity, fitness, bloods, urine, etc.).
- Provided leadership to the CHMS Project Team on technical logistics of physical measures data collection, including equipment procurement, set-up and calibration, laboratory set-up, sample storage and transport, and communication, and liaison with area expertise equivalent from other international surveys .
- Assisted in the planning and managing of a large scale (million dollar budget) Pre-Test data collection; complete with managing Physical Measures Specialists, Phlebotomists, and Administrative employees.
- Developed, collected, processed, analyzed and disseminated statistical health information
- Participated in the writing of reports and articles on the interpretation of surveys results of direct physical measures data.

Fitness Consultant **2000 - 2002**
Fitness Assessment Centre, University of New Brunswick

- Assisted in the operations of non-profit resource centre including: development of funding proposals and business plans, administration of budget, hiring and supervision of part-time staff and volunteers, development and maintenance of a current resource library.
- Collaborated with other health promotion organizations to develop, deliver and evaluate innovative and effective education programs and activity-based initiatives.
- Supervised and administered fitness appraisals, including occupation specific protocols for law enforcement agencies, fire fighters, elite athletes, and special populations.
- Provided individual exercise counselling and prescription.

TEACHING EXPERIENCE

Growth and Development (3rd yr undergraduate) **2010**
Guest lecturer: College of Kinesiology, University of Saskatchewan

Functional Basis of Physical Activity (1st yr undergraduate) **2010**
Guest lecturer: College of Kinesiology, University of Saskatchewan

Exercise and Public Health (penultimate yr undergraduate) **2007-2008**
Pediatric Exercise and Health (M.Sc.)
Kinanthropometry (final yr undergraduate)
Co-taught modules in each of the above courses: School of Sport and Health Sciences, University of Exeter

Introductory Exercise Physiology (2nd/3rd yr undergraduate) **2003 & 2005**
College of Kinesiology, University of Saskatchewan

Fitness Evaluation Techniques (3rd/4th yr undergraduate) **2001 - 2002**
Faculty of Kinesiology, University of New Brunswick

UNDERGRADUATE & GRADUATE STUDENT MENTORING

Pippa Massey- BSc (Hons) Exercise and Sport Sciences **2009**
Institution: School of Sport and Health Sciences, University of Exeter
Title: A comparison between a new two-regression model and indirect calorimetry in a simulated free-living situation
Mentorship role: Second supervisor to Dr. Ann Rowlands

Joseph Eady- BSc (Hons) Exercise and Sport Sciences **2009**
Institution: School of Sport and Health Sciences, University of Exeter
Title: Activity levels during sedentary time in children and adults
Mentorship role: Second supervisor to Dr. Ann Rowlands

Ash Routen- Master of Science by advanced study in Sport and Health Sciences **2008**
Institution: School of Sport and Health Sciences, University of Exeter
Title: The effect of continuous exercise and lifestyle-embedded physical activity upon blood glucose regulation
Mentorship role: Second supervisor to Dr. Ann Rowlands
Additional role: Second Marker of the dissertation (double blinded)

Paul Collings- Master of Science by advanced study in Sport and Health Sciences **2008**
Institution: School of Sport and Health Sciences, University of Exeter
Title: The measured and predicted energy costs of domestic and lifestyle activities in 45- to 55-year-old men and women
Mentorship role: Second supervisor to Dr. Gary O'Donovan

David Spencer- Master of Science by advanced study in Sport and Health Sciences **2008**
Institution: School of Sport and Health Sciences, University of Exeter
Title: Energy expenditure of self-paced domestic activities in adults aged 45- to 55-years
Mentorship role: Second supervisor to Dr. Gary O'Donovan

SERVICE

Grant Capture Ideas Forum (chair) **2007 - 2008**
School of Sport and Health Sciences, University of Exeter

- Acted as a liaison between faculty, staff, and students with respect to organizing and chairing both formal and informal round-table meetings with the view to igniting scholarly discourse and facilitating trans-disciplinary research teams in an effort to increase research grant submission and grant capture.

Invited reviewer for: **2006 - 2010**
- Annals of Behavioral Medicine (1)
- Applied Physiology, Nutrition, and Metabolism (2)
- Biomed Central Medical Research Methodology (1)
- International Journal of Behavioral Nutrition and Physical Activity (3)
- Journal of Physical Activity and Health (1)
- Journal of Science and Medicine in Sport (1)
- Journal of Sports Science and Medicine (1)
- Medicine and Science in Sports and Exercise (7)
- Pediatric Exercise Science (3)

NSERC PGS A&B Grant Reviewer **2004**
Institutional Review Committee Member, University of Saskatchewan

Vice President Academic **2003 - 2004**
Graduate Students' Association, University of Saskatchewan

- Acted as a liaison officer within the university community and the College of Graduate Studies and Research, with respect to academic issues. Represented graduate student interests on a number of university council committees: Planning, Academic Programs, Research, Scholarly & Artistic Work, and Scholarships & Awards, Academic appeals and Grievances

CONTRIBUTIONS TO RESEARCH

Published Manuscripts

1. **Esliger, D.W.**, Rowlands, A.V., Hurst, T.L., Catt, M., Murray, P., Eston, R.G. Validation of the GENEA accelerometer. *Med. Sci. Sports Exerc.* In Press.

2. Takken, T., Stephens, S., Balemans, A., Tremblay, M.S., **Esliger, D.W.**, Schneiderman, J., Biggar, D., Longmuir, P., Wright, V., McCrindle, B., Hendricks, M., Abad, A., van der Net, J., Feldman, B.M. Validation of the Actiheart activity monitor for measurement of activity energy expenditure in children and adolescents with chronic disease. *Eur. J. Clin. Nutr.* Epub:1-7, 2010

3. Fuller, D.L., Muhajarine, N., **Smart Cities, Healthy Kids Research Team.** Replication of the Neighborhood Active Living Potential Measure in Saskatoon, Canada. *Am. J. Prev. Med.* 39(4): 364-367, 2010.

4. Silva, P., **Esliger, D.W.**, G., Welk, J., Mota. Technical reliability assessment of the Actigraph GT1M accelerometer. *Meas. Phys. Ed. Exerc. Sci.* 14: 79-91, 2010.

5. **Esliger, D.W.**, M.S. Tremblay, J.L. Copeland, J.D. Barnes, G.E., Huntington, and Bassett Jr, D.R. Physical activity profile of Old Order Amish, Mennonite, and contemporary children. *Med. Sci. Sports Exerc.* 42(2): 296-303, 2010.

6. Sherar, L.B., N. Muhajarine, **Esliger, D.W.**, and A.D.G. Baxter-Jones. The relationship between girls' (8-14 years) physical activity and maternal education. *Ann. Human Biol.* 36(5): 573-583, 2009.

7. Copeland, J.L., and **Esliger, D.W.**. Accelerometer assessment of physical activity in active healthy older adults. *J. Aging Phys. Activ.* 17(1): 17-30, 2009.

8. Rowlands, A.V., **Esliger, D.W.**, E.L. Pilgrim, A.R. Middlebrooke, and R.G. Eston. Physical activity content of Motive8 PE compared to Primary School PE lessons in the context of children's overall daily activity levels. *J. Exerc. Sci. Fit.* 6(1): 26-33, 2008.

9. Tremblay, M.S., **Esliger, D.W.**, J.L. Copeland, J.D. Barnes, and D.R. Bassett Jr. Moving forward by looking back: Lessons learned from lost lifestyles. *Appl. Physiol. Nutr. Metab.* 33(4): 836-842, 2008.

10. Sherar, L.B., **Esliger, D.W.**, Baxter-Jones, A.D.G., and M.S. Tremblay. Letter to the editor in response to "Incoherence with Studies Using ActiGraph MTI among Children Age 6-12 Years". *Med. Sci. Sports Exerc.* 40(5): 980, 2008.

11. Tremblay, M.S., R.J. Shephard, L.R. Brawley, R. Adams, C. Cameron, C.L. Craig, M. Duggan, **Esliger, D.W.**, W. Hearst, A. Hicks, I. Janssen, P.T. Katzmarzyk, A.E. Latimer, K.A. Martin Ginis, A. McGuire, D.H. Paterson, R. Poirier, M. Sharratt, J.C. Spence, B. Timmons, D. Warburton, K. Young, and L. Zehr. Physical activity guidelines and guides for Canadians: Facts and future. *Can. J. Public Health* 98(Suppl. 2) / *Appl. Physiol. Nutr. Metab.* 32(Suppl. 2E): S218-S224, 2007.

12. Tremblay, M.S., **Esliger, D.W.**, A. Tremblay, and R. Colley. Incidental movement, lifestyle-embedded activity and sleep: New frontiers in physical activity assessment. *Can. J. Public Health* 98(Suppl. 2) / *Appl. Physiol. Nutr. Metab.* 32(Suppl. 2E): S208-S217, 2007.

13. **Esliger, D.W.** and M.S. Tremblay. Physical activity and inactivity profiling: The next generation. *Can. J. Public Health* 98(Suppl. 2) / *Appl. Physiol. Nutr. Metab.* 32(Suppl. 2E): S195-S207, 2007.

14. Tremblay, M.S., R. Langlois, S. Bryan, **Esliger, D.W.**, and J. Patterson. Canadian Health Measures Survey pretest: Design, methods, results, recommendations. *Health Reports.* (Statistics Canada, Catalogue 82-003) 2007; 18(Supplement): 1-10.

15. Stone, M.R., **Esliger, D.W.**, and M.S. Tremblay. Comparative validity assessment of five activity monitors: Does being a child matter? *Pediatr. Exerc. Sci.* 19: 291-309, 2007.

16. **Esliger, D.W.**, A. Probert, S. Connor Gorber, S. Bryan, M. Laviolette, and M.S. Tremblay. Validity of the Actical accelerometer step count function. *Med. Sci. Sports Exerc.* 39(7): 1200-1204, 2007.

17. Sherar, L.B., **Esliger, D.W.**, A.D.G. Baxter-Jones, and M.S. Tremblay. Age and gender differences in youth physical activity: Does physical maturity matter? *Med. Sci. Sports Exerc.* 39(5): 830-835, 2007.

18. Bassett Jr., D.R., M.S. Tremblay, **Esliger, D.W.**, J.L. Copeland, J.D. Barnes, and G.E. Huntington. Physical activity levels and Body Mass Index of youth in an Old-Order Amish community. *Med. Sci. Sports Exerc.* 39(3): 410-415, 2007.

19. **Esliger, D.W** and M.S. Tremblay. Technical reliability assessment of three accelerometer models in a mechanical setup. *Med. Sci. Sports Exerc.* 38(12): 2171-2181, 2006.

20. Pinkoski, C., P.D. Chilibeck, D.G. Candow, **Esliger, D.W.**, J.B. Ewaschuk, M. Facci, J. Farthing, and G.A. Zello. The effects of conjugated linoleic acid supplementation during resistance training. *Med. Sci. Sports Exerc.* 38(2):339-48, 2006.

21. Tremblay, M.S., J.D. Barnes, J.L. Copeland, and **Esliger, D.W.**. Conquering childhood inactivity: is the answer in the past? *Med. Sci. Sports Exerc.* 37(7):1187-94, 2005.

22. **Esliger, D.W.**, J.L. Copeland, J.D. Barnes, and M.S. Tremblay. Standardizing and optimizing the use of accelerometer data for free-living physical activity monitoring. *J. Phys. Activ. Health* 2(3):366-383, 2005.

Chapters in Books or Government Reports

1. O'Donovan, G., **Esliger, D.W.**, and E. Stamatakis. Physical activity, physical fitness and the evolution of physical activity guidelines. In: BASES' guidelines on physical activity in the

prevention of chronic disease, O'Donovan, G. (ed.), Chapter #, pp. #-#, Human Kinetics, UK, In Press.

2. Rowlands, A.V., **Esliger, D.W.**, J., Eady, and R.G. Eston. Empirical evidence to inform decisions regarding identification of non-wear periods from habitual physical activity data, In: The Proceedings of the 25th Paediatric Work Physiology Meeting. Berthoin, S. and Baquet, G. (ed). Routledge: Taylor & Francis Group, UK, Part 7, Chapter 39. 2010.

3. **Esliger, D.W.** and Hall, J. Accelerometry in children. In: Health Survey for England 2008: Physical activity and fitness, Craig, R., Mindell, J., and Hirani, V. (ed.), Volume 1, Chapter 6, Joint Health Surveys Unit, National Centre for Social Research, London, UK. 2009.

4. Chaudhury, M. and **Esliger, D.W.**. Accelerometry in adults. In: Health Survey for England 2008: Physical activity and fitness, Craig, R., Mindell, J., and Hirani, V. (ed.), Volume 1, Chapter 3, Joint Health Surveys Unit, National Centre for Social Research, London, UK. 2009.

5. Sherar, L.B., N.C. Gyurcsik, M.L. Humbert, **Esliger, D.W.**, and A.D.G. Baxter-Jones. Understanding the decline in the physical activity of adolescent girls, In: Children and Exercise XXIV: The Proceedings of the 24th Paediatric Work Physiology International Symposium, Jurimae, T., Armstrong, N., Jurimae, J.(ed). Routledge: Taylor & LLC, UK, Chapter 2, P146-149. 2008.

Invited Presentations

1. **Esliger, D.W.** and Hurst, T. To measure is to know: The health benefits of physical activity. A University of Exeter and Unilever Case Study. (Public presentation to launch an Economic & Social Research Council funded research cluster at the University of Exeter, Devon, UK, November, 2008).

2. **Esliger, D.W.** Accelerometer-based physical activity assessment: A research overview. (Dr. Patty Freedson's research team at the School of Public Health and Health Sciences, Department of Kinesiology, University of Massachusetts at Amherst, MA, USA, October, 2007).

3. **Esliger, D.W.** Objective assessment of physical activity in epidemiologic research: Problems and prospects. (Framingham Heart Survey research team, Boston, MA, USA, October, 2007).

4. **Esliger, D.W.** Physical activity and inactivity profiling: The next generation. (Participated as a commissioned scientist at a Research Workshop Retreat: Advancing the Future of Physical Activity Measurement and Guidelines in Canada [funded by the Canadian Society of Exercise Physiology and the Public Health Agency of Canada]. Kananaskis, AB, Canada, March, 2007).

5. **Esliger, D.W.** Physical activity and inactivity profiling possibilities. *Canadian Society for Exercise Physiology* (Canadian Institute of Health Research Pre-conference Think Tank to Annual General Meeting, Halifax, N.S., Canada, November, 2006).

6. **Esliger, D.W.** Activity monitoring by accelerometry: from calibration to publication. *Healthy Opportunities for Preschoolers (HOP) Research Group, University of Victoria* (Victoria, BC, April 2006).

7. **Esliger, D.W.** Everything you ever wanted to know about accelerometer data reduction and more. *Action Schools BC Research Group, University of Victoria* (Victoria, BC, April 2006).

8. **Esliger, D.W.** Activity monitoring by accelerometry: from calibration to publication. *Medical Research Council, Epidemiology Unit, Cambridge University* (Cambridge, UK, January 2006).

9. Tremblay, M.S., and **Esliger, D.W.** Activity monitoring by accelerometry: from calibration to publication. *Canadian Society for Exercise Physiology* (Annual General Meeting, Gatineau, Que., Canada, November, 2005).

10. **Esliger, D.W.** The use of accelerometers to objectively measure free-living physical activity. *Canadian Health Measures Survey, Colloquium Series, Statistics Canada* (Ottawa, Canada, January, 2005).

Published Abstracts

1. **Esliger D.W.**, A. Probert, S. Connor Gorber, S. Bryan, M. Laviolette, and M.S. Tremblay. Validity of the Actical accelerometer step count function. Applied Physiology, Nutrition and Metabolism 32(S1):S28, 2007.

2. Tremblay M.S., **Esliger, D.W.**, J.D. Bassett, J.D. Barnes, J.L. Copeland, and G.E. Huntington. BMI and fitness of Amish, Mennonite and contemporary-living children. *Obesity Reviews.* 7(suppl.2):229, 2006.

3. **Esliger D.W.**, M.S. Tremblay, D.R. Bassett, J.D. Barnes, J.L. Copeland, and G.E. Huntington. Physical activity profile of Old Order Amish, Old Order Mennonite and contemporary-living children. *Physical Activity and Obesity.* International Congress Satellite Conference Handbook, p.97, 2006.

4. **Esliger, D.W.** and M.S. Tremblay. Divergent trends in the convergent validity of Actical, Actigraph, and RT3 accelerometers. *Physical Activity and Obesity.* International Congress Satellite Conference Handbook, p.84, 2006.

5. Tremblay M.S., **Esliger, D.W.**, K.R. Parker, K.B. Adamo, and C.M.A. LeBlanc. Canadian Learning to be Active in School Study increases physical activity. *Physical Activity and Obesity.* International Congress Satellite Conference Handbook, p.70, 2006.

6. Bassett, D.R., M.S. Tremblay, **Esliger, D.W.**, J.L. Copeland, J.D. Barnes, and G.E. Huntington. Physical activity levels in children of an Old Order Amish community. *Med. Sci. Sports Exerc.* 38(5):S81, 2006.

7. **Esliger, D.W.**, M. Stone, and M.S. Tremblay. The effect of height on the validity of three accelerometer models. *Med. Sci. Sports Exerc.* 38(5):S558, 2006.

8. **Esliger, D.W.**, J.D. Barnes, J.L. Copeland, and M.S. Tremblay. The influence of lifestyle and gender on physical activity behavior in children. *Pediatr. Exerc. Sci.* 17(1):72-73, 2005.

9. Tremblay, M.S., J.D. Barnes, **Esliger, D.W.**, and J.L. Copeland. Seasonal variation in physical activity of Canadian children assessed by accelerometry. *Pediatr. Exerc. Sci.* 17(1):73, 2005.

10. Copeland, J.L., **Esliger, D.W.**, J.D. Barnes, and M.S. Tremblay. Physical activity guidelines for children: are they relevant? *Pediatr. Exerc. Sci.* 17(1):73-74, 2005.

11. **Esliger, D.W.**, M. Stone, and M.S. Tremblay. Intra- and inter-instrument reliability of three accelerometer models. *Can. J. Appl. Physiol.* 29:S44, 2004.

12. Pinkoski, C., P.D. Chilibeck, D.G. Candow, **Esliger, D.W.**, and J. Farthing. Supplementation with Conjugated Linoleic Acid during strength training. *Med. Sci. Sports Exerc.* 36(5):S284, 2004.

13. Tremblay, M.S., J.D. Barnes, **Esliger, D.W.**, and J.L. Copeland. Comparison of physical activity behaviour between Old Order Mennonite and contemporary-living children. *Can. J. Appl. Physiol.* 28:S110, 2003.

14. **Esliger, D.W.**, J.D. Barnes, J.L. Copeland, and M.S. Tremblay. We may know how active our children are, but how are they active? *Can. J. Appl. Physiol.* 28:S50-51, 2003.

15. Tremblay, M.S., J.D. Barnes, **Esliger, D.W.**, and J.L. Copeland. Validity of the PAQ-C self-report physical activity questionnaire for children living traditional vs. contemporary lifestyles. *Portuguese J. Sport Sci.* 3(2):134-135, 2003.

16. Tremblay, M.S., J.D. Barnes, **Esliger, D.W.**, and J.L. Copeland. Fitness level of children living traditional vs. contemporary lifestyles. *Portuguese J. Sport Sci.* 3(2):142-143, 2003.

17. Barnes, J.D., **Esliger, D.W.,** J.L. Copeland, A.D.G. Baxter-Jones, and M.S. Tremblay. Comparing health-related physical fitness between Old Order Mennonite and urban children in Canada. *Med. Sci. Sports Exerc.* 35(5):S13, 2003.

18. **Esliger, D.W.**, M.S. Tremblay, and J.L. Copeland. Does frequency (Hz) and acceleration of movement affect the reliability of the MTI(CSA) Actigraph? *Med. Sci. Sports Exerc.* 35(5):S285, 2003.

19. **Esliger, D.W.**, and G.G. Sleivert. Neuromechanical responses to maximal effort squat jumps. *Can. J. Appl. Physiol.* 27:S15, 2002.

20. **Esliger, D.W.**, and G.G. Sleivert. Calculating maximal mechanical power output: theoretical considerations. *Can. J. Appl. Physiol.* 27:S15-16, 2002.

21. Sleivert, G.G, **Esliger, D.W.,** and P.J. Bourque. The neuromechanical effects of varying relative load in a maximal squat jump. *Med. Sci. Sports Exerc.* 34(5):S125, 2002.

22. Bourque, P.J., **Esliger, D.W.,** and G.G. Sleivert. The inter-day reliability of estimating true muscular strength using twitch interpolation. *Can. J. Appl. Physiol.* 26(5):467, 2001.

23. Copeland, J.L., **Esliger, D.W.**, and M.S. Tremblay. Profile of female activity behaviours. *Can. J. Appl. Physiol.* 26(5):471, 2001.

24. **Esliger, D.W.**, P.J. Bourque, K.B. Englehart, and G.G. Sleivert. Reliability of *Vastus Lateralis* EMG during isometric contractions. *Can. J. Appl. Physiol.* 26(5):477, 2001.

25. Sleivert, G.G., P.J. Bourque, and **Esliger, D.W.**. The relationship between evoked quadriceps force, EMG and voluntary knee extensor strength. *Can. J. Appl. Physiol.* 26(5):512, 2001.

26. Sleivert, G.G., **Esliger, D.W.**, and P.J. Bourque. The reliability of measuring evoked quadriceps force characteristics. *Can. J. Appl. Physiol.* 26(5):512, 2001.

27. Tremblay, M.S., **Esliger, D.W.**, and J.L. Copeland. Physical activity recall compared to accelerometry measurement in females aged 19-69. *Med. Sci. Sports Exerc.* 33(5):S119, 2001.

Conference Presentations

1. Glazer, N.L., Lyass, A., **Esliger, D.W.**, Blease, S.J., Massaro, J., Vasan, R.S., Murabito, J.M. Association of compliance with national physical activity guidelines with CVD risk factors: Assessment using accelerometry in the Framingham Study. *Joint Conference – Nutrition, Physical Activity and Metabolism and Cardiovascular Disease Epidemiology and Prevention.* (Atlanta, USA, March 2011).

2. Glazer, N.L., Lyass, A., **Esliger, D.W.**, Blease, S.J., Massaro, J., Murabito, J.M., Vasan, R.S. Physical activity assessment with accelerometry and relations to CVD risk factors in adults in the community. *Joint Conference – Nutrition, Physical Activity and Metabolism and Cardiovascular Disease Epidemiology and Prevention.* (Atlanta, USA, March 2011).

3. Gibbs, Z., **Esliger, D.W.**, Newton, R., Galvao, D. High vs. low intensity exercise for breast cancer related lymphedema: The effect of a 12-week periodised exercise program on diurnal activity and its relation to fatigue, body composition, and quality of life. *7th State Cancer*

Conference, Cancer Council Western Australia and the Palliative Care Research and Evaluation Unit. (Perth, Western Australia, March 2011).

4. Rowlands, A.V., **Esliger, D.W.**, Hurst, T., Catt, M., Eston, R.G. Comparison of the novel GENEA waveform accelerometer and ActiGraph accelerometer during free-living activities in adults. *3rd International Conference on Physical Activity and Public Health.* (Toronto, Canada, May, 2010).

5. **Esliger, D.W.** The next generation of accelerometer-based physical activity monitoring. In a symposium titled: Accelerometry-based physical activity monitoring: where are we and where are we going? Symposium organizer and presenter at the *2nd International Conference on Physical Activity and Public Health.* (Amsterdam, Netherlands, April, 2008).

6. Sherar, L.B., Gyrusik, N., Humbert, L., **Esliger, D.W.**, and A.D.G. Baxter-Jones. Understanding the decline in the physical activity of adolescent girls. *Pediatric Work Physiology Conference.* (Tallin, Estonia, September 2007).

7. Stone, M., **Esliger, D.W.**, and M.S. Tremblay. Factors affecting the prediction of energy expenditure from accelerometer data. *4th European Youth Heart Study Symposium & Objective Measurement of Physical Activity.* (Odense, Denmark, April, 2006).

8. **Esliger, D.W.**, L. B. Sherar, A.D.G. Baxter-Jones, D.R. Bassett, and M.S. Tremblay. Profiling daily physical activity behaviour: the impact of good and bad weather? *International Congress on Physical Activity and Public Health.* (Atlanta, USA, April 2005).

9. Sherar, L.B., **Esliger, D.W.**, A.D.G. Baxter-Jones, and M.S. Tremblay. Gender differences in physical activity behaviour: does physical maturity matter? *International Congress on Physical Activity and Public Health.* (Atlanta, USA, April 2005).

10. Stone, M., **Esliger, D.W.**, and M.S. Tremblay. Differences in step counts across devices: considerations when working with step counters in youth. *Pediatric Work Physiology Conference.* (Thon, Switzerland, October 2005).

11. Tremblay, M.S., **CHMS Team**. Canadian Health Measures Survey (CHMS) pre-test: methodological overview. *Canadian Public Health Association, Annual General Meeting* (Ottawa, ON, Canada, September, 2005).

12. Tremblay, M.S., S. Bryan, K. Yip, R. Morrison, and **Esliger, D.W.**. Canadian Health Measures Survey (CHMS) pre-test: Self-reported versus measured height, weight and body mass index. *Canadian Public Health Association, Annual General Meeting* (Ottawa, ON, Canada, September, 2005).

13. **Esliger, D.W.**, and M.S. Tremblay. Standardizing and optimizing accelerometer data for physical activity monitoring. *Objective Measurement of Physical Activity: Closing the gaps in the science of accelerometer, Think Tank Meeting* (Chapel Hill, NC, USA, December, 2004).

14. **Esliger, D.W.**, J.D. Barnes, J.L. Copeland, and M.S. Tremblay. Is the physical activity and fitness of rural children declining? *Fifth International Symposium, Institute of Agriculture, Rural, and Environmental Health* (Saskatoon, SK, Canada, 2003).

RESEARCH / TEACHING RELATED FUNDING

Name	Value	Description	Location of Tenure	Period
PHAC: Achieving Healthy Weights in Canada's Communities (consultant)	$211,735	Provide children with healthy eating, physical activity and psychosocial environments to achieve healthy weights.	Saskatchewan Network for Health Services in French	2011
CIHR, Operating Grant: Childhood Obesity Prevention and Treatment (consultant)	$450,000	Working upstream: Effecting healthy children through environmental design	Community Health and Epidemiology, University of Saskatchewan	2009-12
Annual Fund Grant (funded by Development & Alumni Relations)	$9,250	Grant to fund a curriculum-based student experience initiative called: Innovations in Physical Activity Challenge	School of Sport and Health Sciences, University of Exeter	2009-10
Equipment Grant (funded by Unilever plc)	$50,000	Grant to purchase the Cosmed K4 b2b portable indirect calorimeter	School of Sport and Health Sciences, University of Exeter	2007-9
Equipment Grant (funded by Unilever plc)	$5,000	Grant to purchase the IDEEA physical activity monitor and relevant software	School of Sport and Health Sciences, University of Exeter	2007-9
Equipment Grant (departmental)	$20,000	Shared research/teaching grant to purchase 50 accelerometers and relevant accessories.	School of Sport and Health Sciences, University of Exeter	2007-8
Travel Grant (funded by Unilever plc)	$5,000	Networking grant to establish contacts and pursue collaborations	School of Sport and Health Sciences, University of Exeter	2007
CIHR-IMHA, Seed Grant, Co-investigator	$64,985	Validation of accelerometry as a measure of physical activity and inactivity in children with chronic disease	The Hospital for Sick Children, University of Toronto	2007-8
CIHR-INMD Grant, Co-principal investigator	$15,000	Workshop support: Advancing the Future of Physical Activity Measurement and Guidelines in Canada	College of Kinesiology, University of Saskatchewan	2006
Respironics Grant, Co-investigator	$9,800	Contract research: Validity and reliability assessment of the	College of Kinesiology, University of Saskatchewan	2006

		Actical accelerometer		

Notes: All amounts are in Canadian dollars and where necessary were converted from GBP using the exchange rate of the day; CIHR- Canadian Institutes of Health Research; INMD- Institute of Nutrition, Metabolism, and Diabetes; IMHA- Institute of Musculoskeletal Health and Arthritis; PHAC- Public Health Agency of Canada

SCHOLARSHIPS, FELLOWSHIPS, AND AWARDS

Name	Value	Type	Location of Tenure	Period
Research Fellowship (funded by Unilever plc)	$120,000	Externally Funded	School of Sport and Health Science (April) University of Exeter	2007-9
Travel Award	$550	Institutional	College of Kinesiology, University of Saskatchewan (April)	2006
Travel Award	$500	Departmental	University of Saskatchewan (April)	2006
President's Fund Travel Award	$150	Institutional	College of Kinesiology, University of Saskatchewan (Sept.-Aug.)	2006
Devolved Scholarship	$18,000	Institutional/ Departmental	University of Saskatchewan (Sept.-Sept.)	2005-6
NSERC PGS-B	$42,000	National	College of Kinesiology, University of Saskatchewan (Sept.-Sept.)	2003-5
NSERC Top-Up	$6,000	Departmental	College of Kinesiology, University of Saskatchewan (Oct.)	2003-5
Travel Award	$500	Departmental	College of Graduate Studies and Research, University of Saskatchewan (May)	2003
Graduate Travel Award	$500	Departmental	University of Saskatchewan (May)	2003
President's Fund Travel Award	$150	Institutional	University of Saskatchewan (Jan.-May)	2003
Graduate Teaching Fellowship	$11,000	Institutional	University of New Brunswick (May-Aug.)	2003
NSERC PGS-A	$35,950	National	University of Saskatchewan (Sept.-May)	2001-3
Graduate Scholarship	$12,500	Institutional	University of New Brunswick (Sept.-Aug.)	2000-2
Sir George Foster Scholarship	$ 1,200	Institutional	University of New Brunswick (Sept.-May)	1999-2000
Verna MacDonald Scholarship	$ 1,000	Institutional	University of New Brunswick (Sept.-May)	1998-9

Notes: All amounts are in Canadian dollars; NSERC- National Science and Engineering Research Council; PGS-Post Graduate Scholarship

MEMBERSHIPS AND PROFESSIONAL CERTIFICATIONS

- American College of Sports Medicine (member)
- Canadian Society for Exercise Physiology (member)
- International Society for Physical Activity and Health (member)
- North American Society for Pediatric Exercise Medicine (member)
- Professional Fitness and Lifestyle Consultant (certification lapsed)

REFERENCES

Available upon request.