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The Effect of Body Mass Index on Pedometer Accuracy in a Free-Living Environment

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To the Graduate Council:

I am submitting herewith a dissertation written by Brian Matthew Tyo entitled "The Effect of Body Mass Index on Pedometer Accuracy in a Free-Living Environment." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Exercise and Sport Sciences.

Dixie Thompson, Major Professor

We have read this dissertation and recommend its acceptance:

David Bassett Jr., Eugene Fitzhugh, Naima Moustaid-Moussa, Dawn Podulka-Coe

Accepted for the Council:

Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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The Effect of Body Mass Index on Pedometer Accuracy in Adults and Adolescents in a Free-Living Environment

A Dissertation

Presented for the

Doctor of Philosophy Degree

The University of Tennessee, Knoxville

Brian Matthew Tyo

August 2010

Dedication

This dissertation is dedicated to my son, Jacob, for providing absolute joy to my life. You give me a reason to get up each and every morning. I love you and encourage you to dream and love with all your mind, heart, and soul no matter the cost.

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Abstract

The purpose of this dissertation was to determine if the New Lifestyles NL-2000 (NL) and the Digi-Walker SW-200 (DW), waist-mounted devices, yield similar daily step counts as compared to the StepWatch 3 (SW), an ankle-mounted device, worn by adults and children in the free-living environment.

For the first study, fifty-six adults (32.7 ± 14.5 y) wore the devices for seven consecutive days. There were 20 normal weight, 18 overweight, and 18 obese participants. The NL and DW undercounted (pedometer error) similarly in the normal weight and overweight groups (-15.4% to -18.2%, respectively). However, the DW undercounted more than the NL in the obese group (-32.8% vs -23.9%, respectively). Stepwise regression revealed that both the NL and DW had more error (undercounted more) as a greater percentage steps were accumulated while walking slowly. The DW also had more error with greater BMI. Use of the DW in an obese population will result in twice the error as compared to a normal weight population and thus the DW should not be used to determine relationships between walking volume and adiposity

For the second study, 74 children (13 ± 1.1 y) wore the same devices during one weekday. There were 33 normal weight, 21 overweight, and 20 obese participants. The error was determined for the NL and DW, and the values were similar in the normal weight and overweight groups (-10.8% to -15.4%, respectively). The DW undercounted more than the NL in the obese group (-27.3% vs -8.4%, respectively). The NL was very consistent regardless of BMI category, recording 89.1% (-10.8% error), 89.1% (-10.9%

error), and 91.6% (-8.4% error) for the normal weight, overweight, and obese participants, respectively. Stepwise regression revealed that the DW undercounted more in participants with a high weight. Using the DW in obese children of this age group will result in significantly more undercounting when compared to normal weight children. The DW should not be used to determine relationships between walking volume and adiposity in this population. The NL undercounted by ~10%, regardless of BMI category.

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Part III

The Effect of BMI and Step Rate on Pedometer Error in a Free-Living Environment

Part IV

The Effect of BMI on Waist-Mounted Pedometers Worn by Early Adolescents in a Free-Living Environment

List of Abbreviations

ACSM	American College of Sports Medicine
AT	Active Transportation
BMI	Body Mass Index
BMR	Basal Metabolic Rate
BP	Blood Pressure
BRFSS	Behavior Risk Factor Surveillance Survey
CAD	Coronary Artery Disease
CDC	Center for Disease Control and Prevention
CHD	Coronary Heart Disease
CVD	Cardiovascular Disease
DBP	Diastolic Blood Pressure
DHHS	Department of Health and Human Services
DLW	Doubly Labeled Water
DPA	Domestic Physical Activity
DXA	Dual Energy X-Ray Absorptiometry
EE	Energy Expenditure
FBM	Fat Body Mass
HBP	High Blood Pressure
HR	Heart Rate
HRM	Heart Rate Monitoring
IOTF	International Obesity Task Force
IPAQ	International Physical Activity Questionnaire
LBM	Lean Body Mass
LTPA	Leisure Time Physical Activity
MET	Metabolic Equivalent
NASPE	National Association for Sport and Physical Education
NCEP	National Cholesterol Education Program
NHANES	National Health and Nutrition Examination Survey
OOA	Old Order Amish
OOM	Old Order Mennonite
OPA	Occupational Physical Activity
PA	Physical Activity
PAEE	Physical Activity Energy Expenditure
PAL	Physical Activity Level
PAR	Physical Activity Recall
PE	Physical Education
RMR	Resting Metabolic Rate
SBP	Systolic Blood Pressure
TDEE	Total Daily Energy Expenditure
TEE	Total Energy Expenditure
TPA	Transportation Physical Activity

VA	Vigorous Activity
WC	Waist Circumference
WHO	World Health Organization
YRBSS	Youth Risk Behavior Surveillance Survey

Part I

Introduction

Numerous studies support the health benefits of a physically active lifestyle. Physical activity can help decrease the risk of many negative health outcomes including cardiovascular disease, hypertension, stroke, colon cancer, obesity, type 2 diabetes, and depression (20, 24, 32, 37, 39, 52). However, despite the vast amount of evidence in support of a physically active lifestyle there is considerable evidence that men and women are not active enough. Self-reported data from the 2007 CDC Behavioral Risk Factor Surveillance System (BRFSS) indicates that less than half (49.5%) of the population meets the CDC/ACSM minimum recommendations for physical activity (1). Youth (grades 9-12) are not doing better, only 43.7% of the males and 25.6% of the females meet the recommended levels of physical activity (16). Objectively measured accelerometer data from NHANES suggests that <4% of adults, 42% of children 6-11 years of age, and ≤8% children 12-19 years of age meet exercise recommendations (43). Healthy People 2010 has included physical activity and overweight/obesity as two of the ten leading health indicators that will be used to measure the health of the United States over the next 10 years (2). These indicators were selected based upon the ability to motivate action, the availability of data to measure progress, and the importance as public health issues. The next step needs to be made, to increase the number of people meeting the minimum physical activity recommendations.

The ability to recall physical activity is relatively poor, and this is particularly true for low and moderate intensity activity (8). Therefore, it is important to have accurate objective measures of physical activity. The scientific community needs to test objective monitors of physical activity to make sure they are valid for people of all ages and body types in order to accurately quantify the number of people meeting recommendations and determine relationships between physical activity and adiposity.

In 1995, the American College of Sports Medicine (ACSM) and the Centers for Disease Control and Prevention (CDC) recommended that adults accumulate 30 minutes of moderate intensity physical activity on most days of the week (31). This recommendation was meant to encourage people to progress from a sedentary lifestyle and include more moderate intensity physical activity as part of their lifestyles. This recommendation lead to many questions regarding what intensity, duration, and frequency of physical activity was needed in order to meet the requirements. A clarification of the guidelines was published in 2007 (18). This updated recommendation for adults included more specific language describing the requirements for physical activity. The current recommendation for physical activity is a minimum of 30 minutes of moderate aerobic physical activity on five days each week or 20 minutes of vigorous physical activity on at least three days per week. Accumulation of the recommended minutes should be in bouts of 10 minutes or more. This recommendation also allows for a combination of moderate and vigorous intensity physical activity to be performed to meet the recommendation. In 2008, the Department of Health and Human Services (DHHS) issued a report from the Physical Activity Guidelines Advisory Committee that was consistent with the ACSM recommendations and provided detailed evidence supporting the benefits of a physically active lifestyle (3). The committee provided detailed evidence of the protective effects of physical activity for a variety of negative health outcomes and gave recommendations for future research.

Despite having physical activity patterns that are very different from adults, school-aged youth had very similar recommendations (3-5 sessions, 20-60 minutes of continuous high intensity activity per day) (4). In 2001, a study suggested that youth possibly need 120-150 minutes of physical activity per day (17). Similarly, in 2003, NASPE guidelines suggest that children need at least 60 minutes, possibly several hours, of physical activity per day (11). Some recommendations suggest that youth participate daily in 60 minutes or more of moderate to vigorous physical activity (40). Activities should be developmentally appropriate, fun, and include a wide variety. The Physical Activity Guidelines Advisory Committee Report supported these recommendations (≥60 minutes per day of moderate-vigorous PA) and provided detailed scientific support and directions for future research (3)

An alternative to giving a “time” recommendation in minutes per day, as the ACSM/CDC summary statement has done, is to recommend a certain number of total steps per day. This idea of step accumulation was first introduced in the Japanese culture, which recommended 10,000 steps per day This amount of physical activity has been associated with lower blood pressure, decreased subcutaneous fat, and protection against heart attacks (19, 30). Having a step goal of 10,000 steps per day has been shown to positively affect physical activity in previously inactive adults (6, 10, 21). Middle-aged women who accumulated ≥10,000 steps per day of activity were found to have a body mass index in the normal range and women who walked more had a lower body fat percentage (42). Studies have shown that 10,000 steps per day can improve cardiovascular risk factors in previously sedentary populations (28, 41). However, 10,000 steps per day may be too low of a recommendation for the younger population (44). For example, BMI referenced standards for steps per day in children are 12,000 and 15,000 steps per day for girls and boys, respectively (49). This means that girls taking <12,000 steps and boys taking <15,000 steps per day are more likely to be classified as overweight or obese (49). These standards were designed to establish criterion-referenced cut points for physical activity that are related to a healthy body composition in children (49). This level of activity is approximately equivalent to 120 and 150 minutes per day of physical activity (7, 46, 50, 56). This finding is in agreement with current views and recommendations (11, 17). Although there is considerable evidence suggesting the benefits of quantifying steps per day, there is also evidence that some pedometers may not be accurate for people with a high BMI or for people who walk slowly (12).

Physical inactivity is a contributing factor leading to obesity (53, 54). One goal of the Healthy People 2010 is to reduce obesity prevalence to 15% and 5% for adults and children, respectively (2). However, obesity is on the rise, not only in the adult population, but also in children. The prevalence of obesity in adults has risen from 13.3% in 1960 to 32.9% in 2004 (29). In children, 2-19 years of age, the prevalence of obesity has risen from 5.1% in 1971 to 17.1% in 2004 (29). The numbers are even more drastic when the prevalence of overweight is included. In 2004, 66.2% of adults and 33.6% of children were classified as overweight or obese (29). Increasing physical activity can help reduce overweight/obesity (53), which makes the need for accurate and reliable objective measures of physical activity even more important.

Because increased physical activity can help reduce overweight/obesity (53), it is important to accurately quantify physical activity using objective measures of physical activity. However, physical activity assessment can be complex, depending on intensity, duration, frequency, and mode. Methods for assessing physical activity include questionnaires, heart rate monitors, doubly labeled water, direct observation, accelerometers, and pedometers. The appropriate device/method for accurately assessing physical activity is highly dependent upon the population being studied, participant/researcher burden, and the variables of interest. Each device/method has its own advantages and limitations in adults and children (25, 55).

Pedometers are devices that measure walking distance or steps, that are worn on the body. They can be utilized by both adults and children. There are many types of pedometers on the market today. Previous studies in child and adult populations have suggested that some hip-mounted pedometers are more accurate than others (9, 12, 13, 15, 22, 23, 27, 33, 34). Studies have shown that variables such as stepping rate, BMI, waist circumference, tilt angle, and style of clothing may impact accuracy (9, 12, 15, 26, 27, 33, 38). Two common mechanisms used in pedometers are the piezoelectric and the spring-suspended horizontal lever arm. It has been reported that both the piezoelectric and the spring-suspended horizontal lever arm mechanisms tend to undercount at slow walking speeds (12, 15, 23, 27). The data are unclear regarding the effect of BMI on the accuracy of the spring-suspended horizontal lever arm (12, 41). The piezoelectric mechanism does not appear to be significantly influenced by BMI (12). Studies have shown that the spring-levered device will undercount significantly more than the piezoelectric in people with large tilt angles (>10 degrees) in both adults and children (12, 15). Each of these mechanisms has been used to quantify steps taken in the free-living environment in both the adult and child populations (12, 14, 35, 36, 42, 45, 47, 48, 51). Studies using a spring-levered pedometer have shown that individuals with higher BMI values take fewer steps (42, 45). Similar results have been seen in children (5, 22, 51). However, no differences were seen in children with varying BMI when using a piezoelectric pedometer (36). It is possible that studies using a spring-levered device report fewer steps per day due to increased error seen in people with a high BMI. When comparing groups, it is important to utilize pedometers/step counters that are not affected by adiposity or walking speed. The StepWatch is an expensive (>$500) research grade step counter that uses a dual axis accelerometer and attaches to the ankle. Previous research has shown that the accuracy of the StepWatch is unaffected by walking speed (1-4 mph) or BMI (38). Previous research has also shown that the StepWatch is more accurate than waist-mounted pedometers and could be used to validate waist-mounted pedometers (23).

Statement of the Problem

It is important to examine the accuracy of waist-mounted pedometers in the free-living environment using a criterion that is unaffected by adiposity or walking speed. It is also important to compare piezoelectric and spring-levered devices to determine which is more accurate for adults and children. Additionally, it would be valuable to determine the variables (i.e., BMI, step rate, etc.) that affect pedometer accuracy in adults and children.

Statement of the Purpose

The purpose of this dissertation is to determine if piezoelectric and spring-levered devices yield similar step counts compared to the StepWatch-3 in adults during a seven day free-living measurement period. Variables such as walking speed, BMI, waist circumference, and hip circumference will also be examined to determine if these variables influence pedometer accuracy. A secondary purpose is to compare piezoelectric and spring-levered mechanisms to the StepWatch-3 in early adolescents during 24-hours in a free-living environment and to examine which variables (BMI percentile, weight, and maturity offset) contribute to error in the waist-mounted devices.

Significance of these Studies

There have been numerous studies in adults comparing pedometers in a controlled laboratory environment. Until recently, an accepted criterion to examine the accuracy of waist-mounted pedometers in the free-living environment was unavailable. Therefore, it is of significant benefit to investigate the accuracy of waist-mounted pedometers when compared to an accepted criterion in the free-living environment.

Only a few studies have examined the validity and reliability of various pedometers in children and early adolescents. The effect of BMI on pedometer accuracy in early adolescents has not been thoroughly investigated. Additionally, no study has compared piezoelectric and spring-levered pedometers in the free-living environment.

Therefore, it is important to investigate these relationships so researchers can accurately quantify physical activity in children.

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Part II

Review of Literature

The Importance of Physical Activity

Physical activity (PA) was a vital part of the daily lives of our ancestors. Our ancestors were accustomed to physical activity for hunting, gathering, digging, and escaping predators (45). In most industrialized countries today, PA has become disconnected from activities that our ancestors considered essential for daily survival and we have found that energy intake is not necessarily linked to energy expenditure. For example, in most industrialized nations the number of people performing sedentary jobs is on the rise (31). Instead of growing and harvesting crops and animals for food we simply stop by the local grocery store or fast-food chain as we drive home from work. Researchers suggest that modern homo sapiens have changed very little over the past 10,000 years (62) and that basic anatomy and physiology has not changed in the past 40,000 years (45). Ravussin and colleagues (175) suggest that this relatively recent change in lifestyle shows that some genes are susceptible to lifestyle changes (i.e., PA and diet). Simply put, genes that were possibly beneficial in an environment with high levels of PA are now a liability in a relatively sedentary environment. This suggests that if lifestyles were left unchanged by technology diseases associated with a sedentary lifestyle would remain low. From an evolutionary perspective, the sedentary environment of industrialized nations today represents an extreme circumstance and is vastly different from the lifestyle prior to the industrial revolution (45). Because of the known benefits of a physically active lifestyle (7), the importance of a physically active lifestyle is as important now as it was for our ancestors.

History of Physical Activity

Hunter-gatherers such as the !Kung and the Ache help give us an idea of the level of physical activity of our ancestors. Men of these hunter-gatherer tribes reach PA levels of 1.71 and 2.15 for the !Kung and Ache, respectively (45). For comparison, a typical modern "office worker" has a PA level of 1.37 and a "Fitness Enthusiast" (7.5 mph, 60 min/day) has a PA level of 1.84 (45). In order for a typical American to achieve the level of PA seen in these groups, they would need to add approximately a 12-mile walk per day to their current level of PA (45).

Another group of people that can give us insight into the history of PA is the Amish. Many Amish have maintained lifestyles that were common 150 years ago. The Amish still consider farming a principal occupation and is often accomplished without the benefit of the latest technology (19). With this lifestyle, Amish people tend to accumulate >15,000 $\mathrm{MET \cdot min \cdot wk^{-1}}$, as measured by questionnaire (19). This is astounding considering Craig and colleagues used the same questionnaire and found that in modern cities people accumulate only 2500 $\mathrm{MET \cdot min \cdot wk^{-1}}$ (46). Additionally, 10,000 steps per day have been found to be associated with many health benefits (123, 207). Amish men and women accumulate >18,000 and >14,000 steps per day during week days, respectively, and achieve ~10,000 steps per day on Sunday (typically their day of rest) (19). U.S. adults accumulate approximately 5000-6000 steps per day (215, 229). Amish adults seem to be able to maintain this level of activity due to their lifestyle and the lack of impact of modern technology.

This relationship is also seen in Amish children. Esliger and colleagues (71) compared PA of Old Order Amish (OOA), Old Order Mennonite (OOM), and contemporary children (8-13 y.o.) using an accelerometer and an ex post facto design. OOM and OOA children accumulate significantly more moderate and vigorous PA (71-91 min) per day when compared to contemporary children (~50-60 min) (71). Additionally, Bassett and colleagues (18) found that OOA boys and girls (6-19 y.o.) averaged 17,174 and 13,620 steps per day, respectively. Vincent and colleagues (218) reported that American boys and girls (6-12 y.o.) accumulate 13,231 and 10,992 steps per day, respectively This level of activity in the Amish population is achieved despite few organized sport activities.

The Pima Indians are another group that have been studied to determine the effects of environmental and technological advances on PA. To many researchers, the Pima Indians are an ideal population to study the effect of the environment on PA and obesity (72). The Pima Indians of Mexico have experienced relatively little change in environmental conditions and still practice non-mechanized forms of agriculture while the Pima Indians of the U.S. have experienced technological advances in agriculture, irrigation systems, and a westernized diet (216) . The Pima Indians of the U.S. tend to have a higher BMI, less PA, consume more fat, and have approximately five times the prevalence of type 2 diabetes when compared to the Pima Indians of Mexico (184, 189). Using doubly labeled water (DLW), Esparza and colleagues (72) found that Pima Indians residing in Mexico had significantly higher levels of PA (PA levels of 1.97 versus 1.57) and concluded that PA plays a major role in the prevention of obesity in their population.

Simply stated, when Pima Indians live a traditional lifestyle, such as those in Mexico, they remain active and relatively lean with a low prevalence of type 2 diabetes.

Physical Activity Guidelines Advisory Committee Report

In 2008, the Department of Health and Human Services published PA guidelines for adults and youth (7). The goals of these guidelines were to integrate scientific evidence on the relationship between PA and health variables and to supply a summary of the findings along with PA recommendations. In general, physically active people (children, youth, and adults) have higher levels of fitness, lower risk profile for developing a variety of medical conditions, and lower rates of chronic diseases (i.e., diabetes, hypertension, CVD) (7).

The committee concluded that children and youth should accumulate at least 60 minutes of moderate-vigorous PA daily (7). Additionally, children should participate at least 3 days per week performing resistance exercise (large muscle groups of the limbs and trunk), vigorous aerobic exercise (for CV health), and weight-loading exercise (promoting bone health) (7). These activities should be developmentally appropriate to reduce the possibility of injury/overtraining and fun, to keep children and youth interested in maintaining a physically active lifestyle (7).

Adults should generally accumulate a minimum of 30 to 60 minutes of moderate-vigorous PA on at least 5 days per week (~150 minutes per week) (7). This level of PA is associated with a number of health related benefits (i.e., decreased risk of all-cause mortality, CHD, stroke, hypertension, and metabolic syndrome) (7). This level of activity is between 500 to 1000 MET-minutes per week (7). It should also be recognized that participating in as little as 1 hour per week of moderate intensity PA is associated with decreasing risk of all-cause mortality and CHD when compared to a sedentary population (7). Simply stated, moving out of the "least active" category significantly lowers the risks of a variety of negative health outcomes. It is important to quantify the volume of activity needed to maintain or lose weight. The volume of PA needed for people who wish to maintain a healthy weight may be >150 minutes of moderate-vigorous PA per week (780 to 1560 MET-minutes) and people wanting to achieve weight loss may require a larger volume of PA (≥1560 MET-minutes per week) (7).

Additionally, in order to maintain weight loss it may be necessary to achieve 4.4 kcal per kilogram per day (2184-4368 MET-minutes) of PA energy expenditure (i.e., walking for 60 minutes or jogging for 30 minutes) (7). In order to maintain muscle and bone health, improve functional status, and reduce the number of falls in older adults the committee also made resistance exercise recommendations. In general, adults should participate in a progressive resistance program that utilizes all of the major muscle groups at least 2 days per week (7). The program should consist of at least 1 set of 8-12 repetitions of each exercise performed to volitional fatigue, with possible additional benefits progressing up to 3 sets (7).

Physical Activity Trends

For adults, PA can be generally classified into four domains including occupational (OPA), leisure time (LTPA), transportation (TPA), and domestic (DPA). PA in children and adolescents are typically classified as physical education (PE) participation, time spent in vigorous activity (VA), and active transportation (AT) [i.e., bicycling and walking]. Researchers have examined PA in each of these areas and Knuth and Hallal (115) recently published a review of these trends. Moderate intensity PA in children is difficult to quantify due to difficulty in recall and the sporadic nature of their PA.

Occupational trends of PA have been examined in several different countries. For example, Sweden, Finland, England, and the U.S. indicate that OPA is decreasing (25, 31, 134, 192). In England, OPA has seen significant declines in men (43.4% to 38.5%) and women (27.3% to 24.7) from 1991-2004 (192). BRFSS data from the U.S. suggest that the percentage of people reporting a high-PA occupation has been declining slowly, ~30% in 1950 to 22.6% in 2000 (31). Additionally, BRFSS data show that the percent of the labor force reporting low-PA increased from 23.3% in 1950 to 41% in 1970 and has remained relatively stable ever since (31). The declining rates of OPA have been fueled by advances in technology, which tend to reduce or even eliminate the need for manual human labor. For example, most U.S. farms have large equipment that has replaced most of the need for heavy manual labor and the number jobs in agriculture has declined from 12.2% in 1950 to <2% in 2000 (31).

LTPA has shown mixed trends. In Taiwan, LTPA decreased in young adults and was stable in older adults from 2001-2004 (119). However, data from Canada, the U.S., and Finland have all shown recent increasing trends in LTPA (14, 47, 194). Using data from Canada, Craig and colleagues (47) found that those who were sufficiently active in LTPA increased from 24% in 1981 to 49% in 2000. Steffen and colleagues, using data from the Minnesota Health Study, found that participation in LTPA increased from 41%

to 57% in men and from 31% to 47% in women from 1980-2000 (194). Lastly, Barengo and colleagues found that high intensity LTPA increased in Finland in both men (13% to 25%) and women (10% to 18%) from 1972-1997 (14). Taken together, there seems to be a slightly positive trend in LTPA (115). However, data from the BRFSS have suggested that the percent of the U.S. population meeting exercise recommendations has remained unchanged, ~24% from 1990-1998 (34).

Automobiles have heavily influenced the decrease in TPA. Brownson and colleagues (31) have found that trips taken by walking or biking ranges from ~35% for people who do not own a car to ~5% for people who own three cars. Using 2000 U.S. Census Data, Brownson and colleagues (31) found that only 9.4% of American households did not own a car. In fact, for daily travel to work the proportion of trips taken by automobile has increase from 67% in 1960 to 88% in 2000 while those taken by walking or public transit has steadily declined (31). Overall, the automobile has had a large impact on decreasing TPA in industrialized nations.

Technology has certainly decreased the amount of DPA needed in contemporary homes. For example, the development of heating, ventilation, and air-conditioning (HVAC) eliminates the need to gather firewood or coal. Other appliances that significantly decrease the need for DPA include clothes washers and dryers, dishwashers, and the electric/gas stove. This is a vastly different lifestyle compared to the Amish where they do not have the benefits of modern technology (19). Additionally, both Amish men and women participate keeping a family garden (19). Robinson and Godbey (177) found that women spend less time doing housework, decreasing from ~40 hours per week in 1965 to ~30 hours per week in 1995. So it is important to note that not only has the amount of time decreased, but the energy needed for household duties has also decreased. Lanningham-Foster and colleagues (120) found that the calories needed to accomplish household tasks such as washing clothes and dishes using modern technology is very close to RMR. When modern technology is not used the caloric requirement of these household chores is nearly twice as much (120). Technology has had a major influence on decreasing DPA.

In summary, although there have been slight increases in LTPA it does not offset the declines seen in all other domains of PA. Unfortunately, cumulative PA has seen a steady decline.

PA patterns for children are different from adults. Children's activity patterns are typically more sporadic and not as "organized" as adults. PA studies in children typically focus on participation in physical education classes, sport participation, vigorous PA, and fitness.

PE class can supply a significant amount of PA for children. There are several studies that have examined temporal changes in PE participation. Lowry and colleagues (140), using data from the YRBS, found that from 1991-1997 participation in PE declined from 42% to 27% for students in grades 9-12. Additionally, the CDC analyzed data from the YRBS from 1991-2003 and found that participation in PE dropped significantly from 1991-1995 but remained stable from 1995-2003 (6). The general trend for the past 20 years has been a decline in PA from PE class.

Several different countries have observed changes in children's sports participation. From 1974-1995, Swedish children 16 years old (y.o.) increased their participation in sports from 68% to 72% and 53%-61% for boys and girls, respectively (227). However, Australian children 10-13 y.o. have seen a decline in sport participation of 87% to 76% and of 80% o 71% from 1985-1997 for boys and girls, respectively (145). Additionally, Suris and colleagues (198) found that Swiss adolescents 16-20 y.o. increased "no sports participation" from 14% to 21 % and 18% to 31% for males and females, respectively. This data shows mixed results with a trend towards decreased sports participation.

Three studies discuss trends in vigorous PA in children and adolescents. In the U.S., Delva and colleagues (53) used the "Monitoring the Future" survey to observe a decrease in vigorous PA from 1986-2003 in boys, but remained steady in girls. However, a study of seven European countries using the "Health Behavior in School-aged Children" questionnaire found that from 1986 to 2002 self reported vigorous PA to be stable or even slightly increased in 11, 13, and 15 y.o. (180). The only country in this study to show a consistent increase in vigorous PA in boys and girls was Finland (180). In Canada, female students in grades 7-13 decreased vigorous PA 62% to 54% from 1997-2001, with no change detected in boys (103). Additionally, the same researchers found that the 11th grade students decreased vigorous PA during PE class from 22% to 13% (103). Based on these limited studies, vigorous PA seems to be stable or decreasing in children and adolescents.

Trends in physical fitness have also been studied. Eisenmann and colleagues (64) reviewed the trends in peak oxygen consumption among U.S. youth from 1939-1990. This review included only studies that directly measured peak oxygen consumption. The study found no change in boys' peak oxygen uptake, however, girls 15 y.o. and older observed a 20% reduction. Neuromuscular and cardiorespiratory fitness trends were examined in Swedish adolescents from 1987-2001 (65). The researchers found that maximal oxygen uptake decreased 9.2% in boys, but girls remained unchanged. Neuromuscular fitness tests (flexed arm hang, sit-ups, and vertical jump) were all lower in 2001 compared to 1987 (65). An additional study from Sweden found a decrease in aerobic performance from 1974-1995 in conjunction with an increase in body dimensions, including BMI (226). This study suggests that the additional body weight did not lead to an increase in aerobic fitness (226). However, it could not be determined if the increased mass was due to lean body mass (LBM) or fat body mass (FBM). Tomkinson and colleagues (210) reviewed 55 studies of the 20 meter shuttle run test in children and adolescents 6-19 years of age, performed in 11 different countries. This meta-analysis revealed a steady and significant decline of 0.43% of the mean values per year in both boys and girls (210). Taken together, the fitness of youth appear to be declining, particularly boys (115).

In summary, total PA in children and adolescents appears to be decreasing over time (115). Part of the reduction can be attributed to decreased PA in PE class, and possibly decreased participation in sports. Vigorous PA is also declining, which could be contributing to decreasing fitness levels.

Protective Effects of Physical Activity

This section outlines how PA can help attenuate common diseases associated with sedentary behavior, now commonly observed in most industrialized nations. The diseases covered in this section include obesity, type 2 diabetes, cardiovascular disease (CVD), and hypertension.

Obesity

Obesity can be generally defined as excess adiposity (body fat). Burton and colleagues (32) defined obesity as "an excess of body fat frequently resulting in a significant impairment of health." This excess adiposity contributes to increased risk of many diseases including hypertension, type 2 diabetes, stroke, coronary heart disease, and hyperlipidemia (1, 32). Two common methods to estimate adiposity, each with strengths and limitations, are BMI and waist circumference (WC). These measures can be useful to estimate disease risk, health status, and to determine the influence of PA. For example, people who are more physically active tend to have a smaller WC and lower BMI when compared to those who are not physically active. The following sections are descriptions of the history, limitations, and trends of BMI and WC.

BMI

BMI is a common measure to express the relationship of weight and height and is expressed as $kg \cdot m^{-2}$. It is typically referred to as a surrogate measure of adiposity, although it does not differentiate between FFM and FBM. BMI is a term first coined by Keys and colleagues in 1972 (112). Although Keys and colleagues were credited with naming this ratio (BMI), $kg \cdot m^{-2}$ was actually first used by Adolphe Quetelet in the 1800's

(172). However, this variable was not used clinically until after WWII, when clinicians found an increasing need for a reliable and practical index of relative weight for epidemiological and clinical studies (68). Quetelet's Index was not used in scientific research until the 1960's (24, 63, 113), and was not validated until it was used in a Framingham study in 1970 (79). Today, the Quetelet Index is commonly known as BMI and is used to determine weight status in adults and children.

BMI is easily calculated and used in many research areas today. The Center for Disease Control and Prevention (CDC) defines BMI cut points for adults as Under Weight (<18.5), Normal Weight (18.5-24.9), Overweight (25-29.9), and Obese (≥30) (2). For children, the cut points are more complicated due to the various rates of growth and maturation. Because of this, BMI percentiles are used to define overweight and obesity based on age and gender.

In 1994, Himes and Dietz (100), along with an expert panel, recommended that BMI should be used routinely to assess overweight in adolescent preventative services. According to their recommendations, the cut offs were defined as Under Weight (<5th percentile) Normal Weight (5th-84.9th percentile), "at risk for overweight" (85th-94.9th percentile), and overweight (≥95th percentile). In 2005, the IOM recommended that adolescents with a BMI of ≥95th percentile should be classified as obese (116). In 2007, Krebs and colleagues (118) recommended that adolescents with a BMI of ≥85th but <95th percentile should be classified as overweight. In the United States, the current recommendations are based on the CDC gender specific charts (2) and children are classified as Normal Weight (5th-84.9th percentile), Overweight (85th-94.9th percentile), and Obese ($\geq$95th percentile) (118). These recommendations are based strictly on data collected in the United States. For studies using an international adolescent population, the CDC charts would not be appropriate.

Due to this limitation, Cole and colleagues (40) developed a definition of overweight and obesity using an international survey. Six countries (United States, Great Britain, Brazil, Hong Kong, Netherlands, and Singapore) were used in the survey. Percentile curves were drawn for each survey. The curves were drawn so that at the age of 18, the curves passed through the widely used cut off points of 25 and 30 $kg \cdot m^{-2}$ (40). These curves were then averaged to determine age and gender specific cut off points for children 2-18 years of age (40). Other countries have also derived their own BMI curves based on their own local data. These countries include the Netherlands (42), the United Kingdom (41), Italy (141), France (178), Hong Kong (China) (130), and Sweden (135). The most common cutoff points for overweight and obesity are the 85th and 95th percentiles, respectively. It is important to note that these points were selected arbitrarily.

Because of its simplicity, BMI is useful to help describe the physical characteristics of a population. However, BMI does have limitations (117, 170). First, BMI does not discriminate between mass due to lean mass and mass due to fat mass. Therefore, a person with a high amount of lean muscle tissue could be classified as obese, when in reality this individual may not have a high percentage of adipose tissue. Secondly, There is a relatively large standard error ($\pm$5%) of estimating percent fat from BMI (139), so BMI is not a recommended method of body composition for fitness evaluations**.** Thirdly, the relationship between BMI and adiposity may differ among ethnic groups (13, 28, 56, 57, 105), possibly due to different tissue density and varying amounts of lean body mass. For example, people of African American and Polynesian descent tend to have a higher BMI but lower relative body fat percent, while people of Ethiopian and Thai descent tend to have a lower BMI and a higher relative body fat percent (57). However, other studies have suggested BMI is not dependent on ethnicity when comparing black and white adults (88). Additionally, it is also well documented that BMI and body fat percent are dependent upon age and gender (57, 219). For instance, if body fat percentage of a 22 year old male with a BMI of 23 $kg \cdot m^{-2}$ was compared to a 70 year old male with the same BMI, their predicted body fat percentage would be 8-19% and 13-24%, respectively (87). A similar example is revealed when comparing men and women. If a 45 year old female with a BMI of 27 $kg \cdot m^{-2}$ were compared to a male of similar age and BMI, their predicted body fat percentage would be 34-39% and 22-27%, respectively.

BMI has similar limitations in children, only these limitations are further complicated by growth and maturation. For example, there is a large increase in height and weight from 5-18 years of age which results in dramatic changes in BMI (82). It can be difficult to distinguish if BMI is increasing predominately due to fat-free mass (FFM) or fat mass (FM). For instance, BMI in adolescent boys seems to increase predominately due to increases in FFM rather than FM (54). Overall, changes in BMI percentiles may not accurately detect changes in adiposity over time, especially among males and children with a low BMI (54). Additionally, BMI differences among thin children may be the due to FFM (83). However, a BMI for age and gender at the ≥95th percentile of the CDC reference population is moderately sensitive (70%-80%) as a specific indicator of excess adiposity in children (82). This indicates that BMI may be accurate in classifying children with excess adiposity as obese, but may not be accurate in determining adiposity in more normal weight children.

BMI Trends

BMI is used to determine both point prevalence and temporal trends in obesity. In the United States, obesity rates in adults climbed from 15% to 33% from 1980 to 2004 (78, 165). Recent data, from 1999 to 2008, suggests that this rapid increase in obesity has slowed and possibly stabilized at 32.2% and 35.5% among adult men and women, respectively (77). Similar trends are seen in European countries, such as Switzerland and England (144, 230). Marques-Vidal and colleagues (144) found that the prevalence of obesity increased in Swiss adult males from 6.3% in 1992/1993 to 9.4% in 2007, and an increase from 4.9% to 8.5% during the same time period for Swiss women. In England, Zaninotto and colleagues (230) found that the prevalence of obesity increased from 1993 to 2004 from 13.6% to 24% among men and from 16.9% to 24.4% among women. If the current trends continue the projected prevalence of obesity in 2012 will be 32.1% for men and 32.0% for women, which is similar to the current prevalence of obesity in the United States (230). Developing countries such as China are also observing increased obesity prevalence (222). Obesity was calculated using the “Chinese” definition of obesity of ≥ 28 kg·m^{-2}. Obesity prevalence nearly doubled from 1992 to 2002, increasing from 3.6% to 7.1% (222). The global rise in the prevalence of obesity is important to monitor, to justify policy changes, and to help developing countries avoid obesity-related issues commonly seen in countries such as the United States and England.

Trends in obesity prevalence among children and adolescents have also been on the rise. Wang and colleagues (221) have reported on worldwide epidemic of childhood obesity and found that the prevalence of obesity is increasing in most industrialized nations, and developing countries could face similar problems in the future. For instance, in the U.S. between 1980 and 2004 obesity prevalence increased from 6% to 19%. However, there were no significant changes from 2003-2006 and from 2007-2008, leveling off at 16.3% and 16.9%, respectively (164, 166). England has also observed an increase in childhood obesity. From 1984 to 2003, obesity prevalence has increased from 1.2% to 6.0% in boys and from 1.8% to 6.6% in girls and has been accelerating in the most recent years (193). Unless something is done to change the current pattern of increasing obesity prevalence, less developed countries (such as China) will likely follow a pattern similar to the U.S. (222).

Waist Circumference

WC is a common measure used to assess abdominal adiposity. Abdominal adiposity is considered a key component of obesity (186). Excess abdominal adiposity is also considered a risk factor for many obesity-related diseases such as the metabolic syndrome and may be a better predictor of all cause mortality (23), type 2 diabetes (223), and CVD (231) than BMI. WC is typically measured at the smallest circumference of the torso (90). Although a very simple and effective measurement, the literature is inconsistent in identifying the measurement location. Therefore, there is no universally accepted WC location (220). Wang et al. (220) compared four different measurement locations including; immediately below the lowest rib, at the narrowest waist (torso) (33), midpoint between the lowest rib and the iliac crest (124), and immediately above the iliac crest (162). Wang and colleagues (220) found that each site was highly reproducible and the measurement location immediately above the iliac crest had the largest mean value when compared to the other locations. Based on these data, it is important to define the measurement location for consistency and in order to properly evaluate disease risk to set cutoffs.

The ACSM defines sex-specific cutoffs to identify high risk as men with a WC >102 cm and women with a WC of >88 cm, taken at the narrowest part of the torso between the umbilicus and xiphoid process (3). This WC criteria is used in conjunction with BMI to determine disease risk relative to normal weight. Recently, sex-specific criteria have been recommended that can be used independent of BMI category (29). The criteria recommended risk categories for women of Very Low (<70 cm), Low (70-89 cm), High (90-109 cm), and Very High (>110 cm) (29). The criteria for men are Very Low (<80 cm), Low (80-99 cm), High (100-120), and Very High (>120) (29). It is important to recognize that other organizations/groups also utilize WC to help define risk of obesity related disease (4, 98).

The World Health Organization (WHO) and International Obesity Task Force (IOTF) both use sex specific criteria for WC. Both WHO and IOTF define substantially increased risk is defined as ≥88 cm for women and ≥102 for men (4), which is similar to the ACSM criteria. Additionally, the WHO has also defined increased risk as ≥80 cm for women and ≥94 cm for men (98). The National Cholesterol Education Program (NCEP) has also identified WC >102 cm for men and >88 cm for women to be one of the risk factors of the metabolic syndrome.

WC cutoffs can vary based on racial differences (152). For instance, Asians are more prone to obesity-related diseases even at lower BMI or WC cutoffs. Therefore, Chinese have cutoff recommendations of ≥85 cm for men and ≥80 for women (20) and Japanese have cutoffs of ≥90 cm for men and ≥85 cm for women (5). In Koreans, the cutoffs were 85 cm for men and 80 cm for women (127). Additionally, Europeans have established WC cutoffs of ≥80 cm for women and ≥94 cm for men (125). Because of these racial differences, a recent joint scientific statement designed to "harmonize the metabolic syndrome" criteria has been published recommending that WC thresholds for abdominal adiposity be dependent upon the population (10). These recommendations range from ≥80 (Europids) to ≥90 (Japanese) cm in women and ≥94 (Europids) ≥102 (USA) cm in men. This leads to the question of whether these racial cutoffs should be used regardless of their country of residence (10). This question cannot be answered with certainty with the data that are available.

WC can also be used in children and adolescents in order to establish criteria for obesity-related diseases. Defining WC cutoffs for children and adolescents is difficult due to variability of maturation in addition to similar variance issues in adults (i.e., gender & race). Because of these limitations, percentiles or z-scores are often used based on age and gender from a reference population. For example, WC is one variable used to determine risk of the metabolic syndrome. Obesity has been defined as ≥90th percentile

(43) and >75th percentile of the sample population (52). Although there is no clearly defined rationale for choosing these WC percentiles, these values are commonly used to determine obesity status in children because of the ease of measurement and association with abdominal adiposity.

Waist Circumference Trends

As previously discussed, WC is strongly associated with increased abdominal adiposity (38, 206). Current trends in WC paint a very grim picture of the state of obesity in the U.S. According to NHANES data from 1988-1994, the age-adjusted prevalence of abdominal obesity was 38.7% and 47.0% for men and women, respectively (131). Data from 2003-2004 NHANES found that the age-adjusted prevalence of abdominal obesity was 52.1% and 61.3% for men and women, respectively (131). This is a large difference when compared to BMI data from NHANES, suggesting only approximately one-third of U.S. adults are obese (165).

The data do not look any better for U.S. children and adolescents 2-19 years of age. Li and colleagues (132) found a significant increase in abdominal obesity of children. NHANES data shows that the prevalence of abdominal adiposity was 10.5% from 1988-1994 for both boys and girls (132). The prevalence of abdominal adiposity increased to 17.4% and 17.8% for boys and girls, respectively, in the 1999-2004 data (132). Unlike adults, these data were very comparable to the prevalence of overweight/obesity data determined by measuring BMI (132). Abdominal obesity trends in youth from England has shown that 11-16 y.o. have increased from 9% (1977-1987) for both sexes to 28% and 38% for boys and girls, respectively, in 1997 (146). Unlike the

U.S. study, this study from England found that WC has increased at a greater rate than BMI in children 10-20 y.o. (146).

In summary, WC trends in both adults and youth show increasing levels of abdominal adiposity. As with BMI determined obesity, WC determined obesity is increasing, especially in industrialized countries such as the U.S. and England.

Physical Activity and Obesity

PA of approximately 13-26 MET-hours per week can be very beneficial to help people maintain and even reduce weight (150, 188). Recently, reviews reported the role of PA in preventing weight gain and treatment of obesity in adults (81, 106) and children (80). The following are examples of how PA has been associated with decreased obesity in both adults and children.

McTiernan and colleagues (150) studied the effect of exercise on weight and body fat in men and women, 40-75 years of age. This was a 12-month randomized control trial designed to study the effect of moderate-vigorous aerobic exercise (60-85% HR max) performed six days per week. Men and women in the exercise group had significant reductions in weight, BMI, WC, total fat mass, and body fat percent at the end of 12 months when compared to the control group (150). The researchers also examined body composition measures stratified by change in steps per day (150). The results indicated that as change in steps per day increased from <1760, 1760-3520, and >3520 the body composition measures of weight, BMI, total fat mass, body fat percent, intra-abdominal fat, and HC significantly decreased in both men and women (150). They concluded that

60 minutes of moderate-vigorous PA per day was sufficient to reduce body fat in both men and women (150).

Tate and colleagues (204) examined the association between prescribing higher physical activity goals and long-term weight loss. Specifically, their aim was to determine if prescribing 2500 kcal of physical activity per week produced a greater weight loss at 30 months when compared to a 1000 kcal per week prescription using a randomized, prospective design and overweight adults (204). The 2500 kcal group was also encouraged to recruit 1-3 partners and small-group counseling with an exercise coach. The study found that the 2500 kcal group lost significantly more weight compared to the 1000 kcal group through 18 months (204). However, by 30 months there were no differences between the groups (204). These data showed that few individuals continued to follow the exercise recommendations after the treatment ended (204). However, those who were classified as maintaining ≥2500 kcal of activity per week regained only 3.1 kg while the other participants regained 5.9 kg (204). It is important to note at it took at least 12 months for each group to regain the lost weight. Additionally, this study shows that physical activity needs to be incorporated into each individual's lifestyle in order to be effective.

Fogelholm and Kukkonen-Harjula (81) reviewed current literature to determine if PA can prevent weight gain. Based on observational studies, they found an energy expenditure of 1500-2000 kcal per week to be associated with improved weight maintenance (81). To put this in perspective, that level of activity would be equivalent to an 85 kg person running on a treadmill at ~12 METs for 82-109 minutes (1.4-1.8 hrs) per week. If the same person wanted to accomplish this energy expenditure walking at 4 METs, he/she would need to walk for 250-333 minutes (4.2-5.6 hrs) per week. This level of energy expenditure is more than most randomized control trials (81). Furthermore, the authors suggest that new methods to improve adherence are needed in order for this level of activity to be maintained (81). Remember that the Amish accumulate >15,000 $\mathrm{MET} \cdot \mathrm{min} \cdot \mathrm{wk}^{-1}$ of activity. This level of activity (1500-2000 kcal per week) is certainly attainable, however, with today's sedentary lifestyle, especially low occupational PA, it may be difficult to accumulate this level of PA. However, the rewards of improved weight maintenance will certainly be worth the time to reduce health hazards associated with obesity.

The protective effects of PA on obesity can also be seen in children. Kimm and colleagues (114) longitudinally studied the relationship between the changes in PA and BMI in >2000 black and white girls at ages 9 or 10 y.o. and then retested when they were 18 or 19 y.o. Their results indicate a significant relationship between PA and changes in BMI and sum of skinfolds in girls (114). BMI differences between active and inactive girls were 2.98 $\mathrm{kg} \cdot \mathrm{m}^{-2}$ for black girls and 2.10 $\mathrm{kg} \cdot \mathrm{m}^{-2}$ for white girls. Additionally, they provide longitudinal evidence that habitual PA plays a primary role in weight gain, with no apparent evidence that increased energy intake played a similar part. Furthermore, although there were differences in BMI between active and inactive girls at ages 9 or 10 y.o., these differences widened over the next nine years (114).

Gutin and colleagues (97) studied the relationship of moderate and vigorous PA and fatness in male and female adolescents. This observational study was a cross-sectional design that included 421 black and white high school students ~16 y of age (97). Using an Actigraph 7164 accelerometer, the investigators were able to determine the intensity of PA (light-vigorous) and if there were relationships between the intensity of PA and body composition, measured by DXA (97). The investigators concluded that, after adjustment for demographics, adolescents who participated in relatively large amounts of vigorous PA tend to have lower body fat percent (97). For example, this study was in agreement with Ekelund and colleagues (67) who found that European children who accumulated <1 h of PA were significantly fatter than those who accumulated >2 h of PA. Additionally, a more recent study from Ness and colleagues (160) found a strong negative dose response relationship between objectively measured MVPA (Actigraph 7164) and body composition (fatmass and BMI). The associations suggest that even a small increase of 15 minutes per day could significantly reduce childhood overweight and obesity (160).

In summary, the benefits of PA in relation to obesity are clear. PA can have a significant impact on decreasing obesity in both adults and children.

The Influence of PA on Type 2 Diabetes

The effect of PA on the reduction of type 2 diabetes has recently been reviewed (92). Typically, increases in the prevalence of obesity are followed by increases in the prevalence of type 2 diabetes (96). For instance, in 2001 Mokdad and colleagues (154) reported on the prevalence of type 2 diabetes, using BRFSS, stratified by BMI category and found that the normal weight group had a prevalence of 4.1% and the class 3 obese had a rate of 25.6%. As the prevalence of obesity continues to rise, the prevalence of diabetes, especially among youth, could significantly impact health and life expectancy. For example, young adults who are diagnosed with diabetes at age 20 lose, on average, 17 potential years of life and 23 quality of life adjusted years (158). Even more troubling is that the CDC estimates that ~35% of people with diabetes have not been diagnosed. The influence of PA on diabetes could potentially be even more profound for adults and youth than is currently known.

Hu and colleagues (101) compared walking and vigorous PA with risk of type 2 diabetes in women. Using data from the Nurses' Health Study cohort, they found that the relative risk of developing type 2 diabetes decreased with increasing PA, even after adjusting for covariates including BMI (101). Those having the most PA ($\geq$ 21.8 MET-hours per week) reduced their risk of type 2 diabetes by over 25%. Similarly, relative risks were also decreased with increased MET-hours of walking activity, even in women who did not perform vigorous activities (101). Exercise intensity was also related to disease risk. Those who walked >4.8 $km \cdot h^{-1}$ reduced their risk of type 2 diabetes by >40% when compared to those who walked <3.2 $km \cdot h^{-1}$. These results are especially encouraging because walking is a form of PA that is accessible, easily adopted, and rarely associated with injury (101).

Walking programs can also help to significantly improve glucose tolerance. For example, Swartz and colleagues (201) examined the effect of a 10,000 steps per day walking program on glucose tolerance in overweight women at risk for developing type 2 diabetes (201). Eighteen women completed the eight-week program and accumulated a mean of 9213 steps per day and found that the intervention was effective in improving glucose tolerance (201). This shows that PA can help improve glucose tolerance, suggesting that walking may help prevent overweight women from developing type 2 diabetes.

Hu and colleagues (102) prospectively followed >4000 Finnish men and women 45-64 years of age without type 2 diabetes. Their analyses suggest that higher levels of PA were associated with a lower relative risk of type 2 diabetes, even after controlling for BMI (102). Even more importantly, the relative risk of type 2 diabetes in the obese group with low PA had greater than double the risk when compared to the obese group with high PA (102). This shows that regardless of BMI status, increasing levels of PA appears to be protective.

Schmitz and colleagues (181) examined cross-sectional associations between PA obtained by questionnaire and 357 non-diabetic children 10-16 y of age. They found that PA was correlated with lower fasting insulin and greater insulin sensitivity and these findings remained significant even after adjusting for covariates such as BMI (181). Interestingly, these findings were even stronger in children with SBP above the median for the group, which indicates that PA may be even more important in this subgroup for maintaining normal insulin sensitivity. These researchers went on to recommend that, based on their findings, more attention should be focused on PA in children (181).

Nassis and colleagues (159) examined the effects of a 12-week aerobic exercise training program on insulin sensitivity in 9-15 y.o. overweight and obese girls. The aerobic training was designed to encourage the children to maintain a HR above 150 beats per minute for ~40 minutes three days per week (159). The main finding from this study was that aerobic training improved insulin sensitivity in overweight and obese girls (159). Most importantly, this suggests that PA is linked with insulin sensitivity independently of adiposity (159).

Recently, a study from van der Heijden and colleagues (217) investigated the effect of an aerobic exercise program on post-pubertal sedentary lean and obese adolescents. The participants exercised at an intensity ≥70% of peak oxygen uptake for 12 weeks (30 minutes per day, 4 days per week). The study found that peripheral insulin sensitivity increased by 35% and 59% for the lean and obese groups, respectively. Also, hepatic insulin sensitivity increased by 19% and 23% for the lean and obese groups, respectively. It appears this level of activity is beneficial to improve peripheral and hepatic insulin sensitivity in both lean and obese sedentary adolescents.

Overall, the importance of PA in adults and children is clear. PA can improve glucose tolerance and insulin sensitivity, and reduce type 2 diabetes in adults and children.

The Influence of Physical Activity on Cardiovascular Disease (CVD)

Physical activity is beneficial for the management of CVD risk factors in adults (107) and children (86). It is well established that atherosclerosis begins even at very young ages (21, 179). Trends in CVD risk factors have decreased from 1971-2000, except for diabetes (96). However, recent projections indicate that the prevalence of obese 35 year olds could increase to ~37% for men and ~44% for women by 2020, which could cause the prevalence of CHD to increase by 16% (22). The protective effects of PA and intensity of PA on CVD in both adult and adolescent populations will be addressed in this section.

Sesso and colleagues (185) examined the relationship between PA and coronary heart disease (CHD) in >12,000 men from the Harvard Alumni Study. PA index (energy expenditure in kJ·wk^{-1}) was calculated using questionnaires. Those men who accumulated ≥4,200 kJ·wk^{-1} (~1000 kcals) reduced their risk of CHD by 20%. Vigorous PA (>8,400 kJ·wk^{-1}) was also associated with 10-20% reduction in risk of CHD. This study also found that older men (≥60 y.o.) with one coronary risk factor who expended ≥4,200 kJ·wk^{-1} had no increased risk when compared with physically active men with no risk factors. Additionally, men who walked ≥5 km·wk^{-1} reduced risk of CHD 13% when compared to men who walked ≤5 km·wk^{-1}, further suggesting that PA can significantly reduce the risk or CHD.

Manson and colleagues (143) compared walking with vigorous exercise for the prevention of CVD in in >70,000 post-menopausal women from the Women's Health Initiative Observational Study. The significant finding from this study was that both vigorous and walking activities were found to have similar protective effects against CVD events. For example, an energy expenditure of 16.7 MET-hours per week of walking and 210 minutes of vigorous activity were found to reduce risk of CAD by 32% and 24%, respectively. This is roughly equivalent to women either walking briskly or exercising vigorously 2.5 hours per week, which supports the current recommendation of at least 30 minutes of moderate-vigorous PA most days of the week (143).

Similarly, Nordstrom and colleagues (163) found similar relationships studying the longitudinal relationship between leisure time PA and the three-year progression of carotid atherosclerosis. Their results indicate that PA during leisure was inversely associated with the progression of atherosclerosis, measured by carotid intima-media thickness. Additionally, the benefits were graded, with benefits moving from sedentary to moderate and from moderate to vigorous activity. Vigorous activity was defined as sweating at least 3.5 times per week. These results show that there are increased benefits in moderate PA, with even more benefit by increasing intensity to vigorous.

There is also evidence that PA is important in protecting children from CVD. For example, Andersen and colleagues (11) examined the cross-sectional relationship between PA and clustered cardiovascular risk in 1732 European children 9 and 15 years of age. Physical activity was objectively measured using the Actigraph 7164 accelerometer. PA was separated into quintiles, in which the highest PA quintile served as the referent group. The referent group achieved 167 and 131 minutes of >2000 cpm for 9 and 15 year olds, respectively. The lower four PA quintiles had 2-3 times greater clustered cardiovascular risk than the referent group. This study suggests that children may need to accumulate >2h. of moderate-vigorous PA every day to prevent clustering of CVD risk factors. This level is two times the current recommendation of at least 1 hour per day (196).

Anderssen and colleagues (12) examined the cross-sectional relationship between low cardiorespiratory fitness as a predictor for clustering of CVD risk factors in 9 and 15 year old European children, using data from The European Youth Heart Study.

Cardiorespiratory fitness was measured on a cycle ergometer. The study found strong associations between cardiorespiratory fitness and clustered CVD risk factors.

Taken together, there is strong evidence that CVD risk factors can be reduced in adults and children by increasing moderate-vigorous PA.

The Influence of Physical Activity on Hypertension

The effect of exercise on hypertension has recently been reviewed (74). Hypertension is a significant problem for all age groups in the United States and it has been suggested that blood pressure levels during childhood and adolescence track into adulthood (122). Trends in hypertension prevalence of U.S. adults aged 60 and older was recently examined by Ostechega and colleagues (168) using NHANES data from 1988 to 2004. The prevalence of hypertension increased from 58% to 67% from 1999 to 2004. Similarly, Fields and colleagues (76) examined the burden of hypertension and found an increase in the prevalence of hypertension to an estimated 65 million in 1999-2000, which was an increase of 15 million (23%) from 1988-1994. High blood pressure (HBP) trends in children and adolescents have also been examined by Din-Dzietham and colleagues (58). After examining 40-year trends, they concluded that HBP has been on the rise since the late 1980’s after a long period of a decreasing trend, with a current prevalence of 3.7% (58). The rise in HBP seems to occur ~10 years after increases in obesity at the population level, with abdominal obesity seemingly accounting for part of the trend (58). PA has been shown to be beneficial to help decrease BP in both adults and children.

Reaven and colleagues (176) investigated the cross-sectional relationship of LTPA on BP in women (50-89 yrs). This study showed a dose-response relationship between PA and both SBP and DBP. SBP in the heavy, moderate, and light PA groups was lower than the sedentary group by 13, 9, and 7 mmHg, respectively. For the same groups, DBP was lowered by 5, 3, and 1 mmHg, respectively. The decreased BP was independent to changes in obesity and insulin levels. Based on their findings, the authors suggest that even light and moderate intensity PA is helpful lowering BP in older women.

Ishikawa-Takata and colleagues (104) examined the dose-response relationship of an 8-week exercise training program and BP in 207 untreated subjects with stage 1 or 2 essential hypertension. Exercise intensity was standardized at 50% of estimated maximal oxygen consumption. This study found that SBP can be reduced by10-15 mmHg with exercise lasting >60 minutes per week, which is clinically significant (104). DBP showed significant reductions, but not as much as the SBP, of 5-7 mmHg with exercise durations lasting ≥30 minutes per week (104). This study shows that previously sedentary subjects with hypertension can significantly reduce their BP with rather modest increases in PA (104).

Tanaka and colleagues (203) examined the effect of 10 weeks of swimming at 60% of VO2max 3 days per week for 30-45 minutes on resting BP in individuals with hypertension. Similar to results from Reaven et al. (cross-sectional study) (176), subjects in this intervention study reduced their SBP and DBP by 7 and 3 mmHg, respectively. Additionally, this study shows that swimming was a suitable modality to significantly decrease BP in individuals with hypertension.

Increasing daily walking has been shown to improve SBP and DBP in postmenopausal (156) and overweight (201) women. Moreau et al. (156) increased daily walking of postmenopausal women by 3 $\mathrm{km \cdot d^{-1}}$ using the Digi-Walker DW-500 to estimate walking distance. SBP was reduced by 11 mmHg at the end of the 24-week intervention and DBP was unchanged. Swartz and colleagues (201) provided participants with a goal of 10,000 steps per day using the Digi-Walker SW-200 pedometer. By the end of the eight-week program SBP and DBP decreased by 8 mmHg and 5 mmHg, respectively. Taken together, moderate intensity activities such as walking can significantly improve SBP and DBP.

Studies examining the effect of exercise on SBP and DBP in children have yielded mixed reviews. A meta analysis of randomized control trials in children and adolescents examining the effects of at least 8 weeks of exercise on SBP and DBP was performed by Kelly and colleagues (110). They found that SBP and DBP were reduced by only 1% and 3%, respectively (110). The authors acknowledged the need for more studies in hypertensive kids and adolescents.

McMurray and colleagues (149) studied the effects of increasing aerobic activity in a school-based intervention (physical education class). The study included 1140 youth, 11-14 y of age and were separated into education only, exercise only, education & exercise, or control groups. After only eight weeks of 30 minutes of aerobic activity three days per week DBP decreased 4.8 mmHg and SBP decreased 2.8 mmHg, however only the DBP was significantly lower than the control group. This suggests that increasing the aerobic component of a physical education class could be beneficial and can reduce age-related increases in blood pressure that normally occurs with maturation of adolescents (149).

Observational studies examining the relationship between PA and blood pressure in children and adolescents is not well understood. Studies have typically used questionnaires to estimate PA. However, children and adolescents typically have difficulty with PA recall. Leary and colleagues (126) attempted to overcome this limitation by using the Actigraph AM7164 in a prospective, population-based study of 5505 children 11-12 y of age. This study found an association between increased levels of PA and lower levels of blood pressure. Higher volumes of PA, not intensity, were associated with lower blood pressure (126).

More recently, Farpour-Lambert and colleagues (75) performed a randomized controlled trial with 44 pre-pubertal children 8-10 y of age. The groups were separated into obese exercise, obese control, and lean group. The lean group was used simply for baseline comparisons. The intervention consisted of three 60-minute sessions per week at an intensity of 55-65% of individual maximal oxygen consumption followed by strength training of the arms, legs, and trunk (2-3 sets of 10-15 repetitions). They observed a significant decrease in SBP and DBP, which ranged from 7-12 and 2-7 mmHg decrease for SBP and DBP, respectively (75). This lead to profound decreases in the proportion of children with hypertension, dropping from 50% to 37% at 3 months and 29% at 6 months (75).

Significant improvements in BP, especially SBP, can be made in adults and children by increasing the volume and intensity of PA.

The Influence of Diet and Various Behaviors on Obesity

There are many dietary habits and behaviors that can contribute to treating overweight and obesity. For instance, Spear and colleagues (190) recently reviewed recommendations for treatment of child and adolescent overweight and obesity. Additionally, Thompson et al. (208) recently reviewed recommendations for treatment of obesity in adults. This section will focus on the relationship of obesity with fruits and vegetable consumption, sweetened beverage consumption, eating breakfast, eating meals away from home, and television viewing.

Fruits and vegetables are typically considered low-energy dense foods because they contain a low amount of energy for a given volume of food (191). This can help people feel satisfied after a meal. Case-control studies in children have found that the relationship between fruit consumption and adiposity are mixed, with some finding an inverse relationship (161), and others finding no relationship (26) . Studies have not found a relationship between vegetable consumption and adiposity, however, a relationship between fruit and vegetable consumption and decreased adiposity has been reported (161). Most importantly, no study has reported a relationship between fruit and vegetable consumption and increased adiposity in children (190). In adults, several studies have found an inverse relationship between fruit and vegetable consumption adiposity (95, 209). Taken together, the consumption of fruits and vegetables has been associated with decreased adiposity.

Consuming sweetened beverages (i.e., soft drinks and sweetened fruit drinks) can lead to increased caloric consumption and weight gain (142). Recently, reviews have described the association between sweetened beverage consumption and increased adiposity in children (190) and adults (55). In children, consuming large amounts of sweetened beverages is a risk factor for obesity (190), however, the long term evidence associating sweetened beverage consumption with increased body weight in adults remains unclear (55).

Data support observations that obese children are more likely to skip breakfast, however, the data are limited and the definition of "breakfast" remains inconsistent (190). A recent review found that children and adolescents in Europe who ate breakfast had reduced risk of becoming overweight or obese (202). Studies in adults have found that those who have lost weight and kept it off typically ate breakfast. For instance, Wyatt et al. (228) reported that adults achieving long-term weight loss (lost 32 lbs and kept the weight off for 6 years) regularly ate breakfast, only 4% reported never eating breakfast. Eating breakfast may reduce fat intake, limit snacking throughout the day, and is associated with adults who have maintained weight loss (61, 228).

Eating meals away from home, specifically "fast-food" establishments, may be associated with increased adiposity in adolescents (190). For instance, Taveras et al. (205) found that more fried foods eaten away from home was associated with increased BMI in older children and adolescents who reside in the United States. This relationship has not been found in non-school aged children in other countries, such as Japan (197). The greater number of fast-food restaurants in a given area is associated with a higher individual–level BMI and risk of being obese (151). Additionally, Peieira et al. (169)

found that consumption of fast-food has been strongly associated with increased body weight in adults (18-30 y.o.).

Recent reviews in children and adults have found that television viewing is associated with increased food and beverage consumption and decreased PA (39, 190). For instance, a randomized control study found that increased television viewing was associated with increased energy intake and decreased energy expenditure (37) Additionally, Cleland et al. (39) found that women viewing >3 hours of television per day had a higher prevalence of abdominal adiposity ($\geq$88 cm) compared to women watching <1 hour per day. Moderate abdominal adiposity (94-101.9 cm) was associated with men viewing >3 hours per day (39).

Objective Monitoring

Objective monitoring of PA typically involves wearing devices on the body to monitor ambulatory movement or physiological responses to PA. The most common objective monitoring devices include pedometers, accelerometers, and heart rate monitoring. A method considered a criterion to determine energy expenditure is doubly labeled water (DLW).

Doubly Labeled Water

Doubly labeled water (DLW) is considered the "gold standard" for the assessment of total daily energy expenditure (TDEE) in the free-living environment. DLW contains naturally occurring stable isotopes of deuterium (^{2}H) and oxygen-18 (^{18}O). The procedure requires the subject to drink a known volume of DLW based on body mass

(93). The isotopes are used as metabolic tracers to monitor their elimination rates over time to measure total CO_2 production. Essentially, ^2H will decrease because of the turnover of H_2O and ^{18}O will decrease due to both H_2O turnover and CO_2 production. CO_2 production can be measured by taking multiple urine specimens to measure the disappearance of ^2H and ^{18}O, which can be used to estimate TDEE (225 K. F. in ch 9 and Starling, R.D. in ch 12 #2587). This information in conjunction with measurements of resting metabolic rate (RMR) and thermic effect of food (TEF) via indirect calorimetry can complete the estimate of physical activity energy expenditure (PAEE) (225 K. F. in ch 9 and Starling, R.D. in ch 12 #2587).

The DLW technique was first developed on mice by Lifson and colleagues (133) in the 1950's. Many studies have used DLW as the "gold standard" for the measurement of energy expenditure (EE) in adults and children (89, 129, 136, 174). For instance, Gardner and colleagues (89) compared PA assessed via a pedometer (Omron), accelerometer (Caltrac), and questionnaire (Minnesota LTPA Questionnaire) to DLW in 22 older people with peripheral arterial occlusive disease (PAOD) for a period of 10 days. This study found the accelerometer to be highly correlated to PAEE (R=0.834). The pedometer was also significantly correlated (R=0.614) to PAEE measured by DLW, although to a lesser degree than the accelerometer, while the questionnaire was not significantly correlated with PAEE. This study concluded that PA in PAOD patients could be accurately estimated via accelerometer, and to a lesser extent with a pedometer, in the free-living environment.

Leenders and colleagues (129) used DLW to evaluate the accuracy of two accelerometers (Tritrac and CSA), a pedometer (Digi-Walker 500), and seven day physical activity recall (PAR) questionnaire in 13 women. Free-living PA was assessed for seven consecutive days. PAEE was calculated from the devices using regression equations. PAEE from the PAR was not significantly different from the DLW method. However, the Tritrac, CSA, and Digi-Walker 500 (hair spring device) significantly underestimated PAEE by 35%, 59%, and 59%, respectively.

Ramirez-Marrero and colleagues (174) used DLW as the criterion to compare methods to estimate PAEE in 12 African American boys and girls (7-10 years of age). The Tritrac-R3D accelerometer, Digi-Walker SW-200, and the Self Administered Physical Activity Checklist (SAPAC) were compared simultaneously over seven consecutive days in the free-living environment. DLW PAEE adjusted for body weight was significantly correlated to the Tritrac-R3D activity counts (r=0.85) and the Digi-Walker SW-200 step counts (r=0.76). This study shows that the Tritrac-R3D and Digi-Walker SW-200 are suitable for evaluating PA in 7-10 year old children.

Although DLW has been used as a criterion in many studies it does have limitations. Because DLW is typically performed for 7-21 days and measures the average TDEE it does not have the ability to determine type, duration, or intensity of PA. Additionally, RMR and TEF must be estimated via other techniques (i.e., indirect calorimetry) in order to calculate PAEE. Another major limitation is the high cost. Therefore, studies using DLW as the criterion typically have a small sample size (~20 participants or fewer).

Pedometers

Thomas Jefferson is commonly given credit for inventing the pedometer. However, Leonardo da Vinci was more likely the inventor of the first pedometer over 500 years ago (44). Leonardo's pedometer resembled a clock, using a series of gears attached to a pendulum that made contact with the leg. As a person walked, the leg moved the pendulum and the gears would register the steps. Modern pedometers are typically worn on the waist at the midline of the thigh. However, some pedometers now have the ability to be worn on the ankle, wrist, or even shoe. Pedometers can provide valuable information on ambulatory activity, such as walking. Unfortunately, early pedometers were generally unreliable and inappropriate for research (91, 111, 224). These pedometers were typically described as fragile and inaccurate. For instance, Kemper and Verschuur (1977) (111) examined the validity and reliability of 2 pedometers (Russian and German) during walking and running in 58 boys (12-18 y of age). The German pedometer underestimated steps by 66% at 2 $km \cdot h^{-1}$ and overestimated steps by 8.6% when running at14 $km \cdot h^{-1}$. The Russian pedometer underestimated steps by 88.8% while walking at 2 $km \cdot h^{-1}$ and overestimated steps by 9.0% while running at 14 $km \cdot h^{-1}$. In addition, Gayle and colleagues (1977) (91) found that pedometers showed inconsistent results, especially at slow walking speeds and Washburn and colleagues (224) found pedometer accuracy to be inconsistent and to vary with the speed of walking or running.

Pedometers have become much more technologically advanced devices. Many pedometers have the ability to estimate distance walked and EE in addition to counting steps. The most common pedometer mechanisms include a horizontal spring-suspended lever arm and the piezoelectric accelerometer. Both devices are typically placed on the waist in line with the long axis of the thigh. The spring-suspended lever arm moves up and down in response to accelerations that occur at the hip (51) and requires an acceleration of at least 0.35 g to count a step (214). Piezoelectric mechanisms typically consist of a piezoelectric element and a seismic mass inside an enclosure (36) and typically require an acceleration of at least 0.30 g to count a step (214). Piezoelectric mechanisms can be manufactured so that the seismic mass causes the piezoelectric mechanism to undergo deformation (like a ball on the end of a stick) or direct compression (like a sandwich) (36). These physical deformations cause acceleration signals. Due to manufacturing advancements, piezoelectric mechanisms are being made smaller (even to the "nano" size) allowing multiple accelerometers to be used in a single device. The ability to use multiple accelerometers within other devices could certainly have advantages. For instance, they could be placed inside every-day devices (watches, cell phones, etc.) so people would not need to wear a separate pedometer to measure steps. Having multiple accelerometers could possibly make them more accurate and less susceptible to counting errors due to waist circumference, style of clothing, or device tilt. Software programs to download, store, and evaluate PA levels of the wearers make the use of many accelerometers much easier than in the past.

Because the accuracy of older mechanical pedometers was rather poor, Bassett and colleagues (16) evaluated the accuracy of five electronic pedometers for measuring distance walked. This study was designed to determine the accuracy while walking on a sidewalk course, compare accuracy relative to different surfaces (concrete vs rubber track), and to determine the effects of walking speed on pedometer accuracy. The Yamax Digi-Walker was found to be the most accurate for the sidewalk portion of the test, measuring 100.7% and 100.6% of the steps taken on the left and right hips, respectively. The pedometers were found to be unaffected by walking surface. However, all the pedometers tended to underestimate steps at slower walking speeds (i.e., $54\ \text{m}\cdot\text{min}^{-1}$).

In a follow-up study Bassett and colleagues (17) examined the validity of pedometers and motion sensors under free-living conditions by using a portable indirect calorimeter, K4b^2. The Yamax Digi-Walker tended to overestimate EE by ~1 MET during walking activities but underestimated EE during all other activities such as housework, family care, conditioning and recreation. The Digi-Walker had a modest correlation between the displayed EE and the K4b^2 (r=0.493). This is probably due to the pedometer's inability to measure arm motion and other non-ambulatory movements.

Schneider and colleagues (183) examined the accuracy and reliability of 10 pedometers for counting steps during a 400 meter walk at a self-selected pace. Of the 10 pedometers, 8 of the pedometers had mean values that were not significantly different from steps counted by the investigator. There were 3 pedometers (Kenz, NL-2000, and Digi-Walker) that were the only pedometers to be within ±3% of the actual steps taken 95% of the time with an intra-model reliability >0.99. One interesting aspect of these pedometers is that the most accurate pedometers were all made in Japan, which has a relatively strict margin of error for the manufacturing of these devices (<3%), established by the Japanese Ministry of Industry and Trading Regulations (99).

It is important to determine the accuracy of pedometers during controlled, laboratory studies. However, it may be even more important to determine the accuracy of pedometers during free-living conditions, where people actually utilize the devices. It is not feasible to manually count steps taken during an entire day. Therefore, the use of a criterion device is necessary. Schneider and colleagues (182) used the Digi-Walker as the criterion device to compare 13 different pedometer models. The agreement of the devices to the Digi-Walker varied greatly. Pedometers ranged from overestimating by >3600 steps to underestimating by >2,000 steps. The conclusion of this study was that the Kenz (piezoelectric), Digi-Walker SW-200 (spring-levered), New Lifestyles NL-2000 (piezoelectric), and Digi-Walker 701 (spring-levered) were suitable for most research purposes. It is important to note that the average BMI of the subjects was 25.8 ± 4.1 $kg \cdot m^{-2}$. Therefore, very few subjects were classified as “obese.” Further research was needed to understand any possible effect of BMI on the accuracy of waist-mounted pedometers and possible differences between mechanisms. Currently, there is conflicting evidence regarding the effect of adiposity (BMI, waist circumference, and tilt angle) on the accuracy of waist-mounted pedometers. However, growing evidence suggests that some pedometers are prone to measurement error when worn by obese individuals.

Crouter and colleagues (51) examined differences between spring-levered and piezoelectric devices in overweight and obese adults using the NL-2000 (piezoelectric) and Digi-Walker SW-200 (spring-levered) at various speeds on a treadmill. This study found that the both pedometers became less accurate with decreasing walking speed. However, the slow walking speed affected the SW-200 more than the NL-2000. The accuracy of the NL-2000 was not affected by BMI, waist circumference, or the tilt of the pedometer. The SW-200 was found to be less accurate with greater BMI and waist circumference at speeds of 80 $m \cdot min^{-1}$ and slower (51). Additionally, the tilt of the pedometer seemed to be the most important factor influencing accuracy across all speeds (51). A subpart of this study included 36 participants in a 24-h study while wearing the devices simultaneously. The pedometers recorded an average of 7662 and 6632 for the NL-2000 and the SW-200 for all subjects, respectively. The SW-200 recorded significantly fewer steps (>13%) than the NL-2000. No comparisons were made among different BMI categories.

Other studies have also examined the relationships studied by Crouter and colleagues. For example, Swartz et al. (199) examined the effects of BMI on the accuracy of the Digi-Walker (SW-200) and also studied the optimal placement of the device (on the waist in line with the anterior thigh, mid-axillary on the hip, or back in line with the posterior thigh). Their results indicated there were no differences in pedometer accuracy for the different placements. However, there was a trend for the front placement to be the most accurate. Unlike Crouter and colleagues (51), Swartz et al. (199) found that the SW-200 was accurate at speeds >80 $m \cdot min^{-1}$ in all subjects and regardless of BMI classification the SW-200 undercounted by 7-20% at speeds <80 $m \cdot min^{-1}$. This suggests that BMI does not affect the accuracy of the SW-200. In agreement with Swartz and colleagues, Elsenbaumer et al. (69) also found that a spring-levered device (DW-200) was not affected by BMI when participants (16 normal, 8 overweight, 11 obese) walked at self-selected speeds. However, recent evidence from

Dock and colleagues (59) have suggested that both spring-levered and piezoelectric devices are affected by tilt angle. Using a gimbal to artificially alter the tilt angle of the devices, they found that the piezoelectric device was significantly less accurate when the tilt angle was $\pm 10°$ at 67 $\text{m}\cdot\text{min}^{-1}$, $\pm 20°$ at ≤ 80.4 $\text{m}\cdot\text{min}^{-1}$, and $\pm 30°$ at ≤ 93.8 $\text{m}\cdot\text{min}^{-1}$. The spring-levered device was significantly less accurate when the tilt angle was +10° at ≤ 80.4 $\text{m}\cdot\text{min}^{-1}$, $\geq \pm 20°$ at all treadmill speeds, and -10° at all treadmill speeds. They concluded that the combination of higher tilt angles and slower walking speeds can have a large impact on pedometer accuracy.

Because of the variability of pedometer position (i.e., style of clothing and position of the pants on the hips) and the possibility of adiposity (i.e., BMI and waist circumference) affecting the accuracy of waist-mounted devices, the development of devices that can be worn on the ankle, virtually unaffected by adiposity, position, or speed of walking, could prove to be extremely valuable. Shephard and colleagues (187) examined the accuracy of a two-dimensional accelerometer-based ankle-mounted pedometer (StepWatch) during a variety of ambulatory activities (400-meter walk, stair ascending/descending, and 10-meter walk) to a waist-mounted spring-levered pedometer (Sportline). The authors concluded that the StepWatch was the superior device and, most importantly, was not affected by BMI. Karabulut and colleagues (109) added to Shephard's findings by comparing two waist-mounted and two ankle-mounted pedometers during treadmill walking, non-ambulatory activities (heel tapping, leg swinging, car driving, and cycle ergometry), and during a free-living condition (24-h study). The StepWatch was extremely accurate even at very slow walking speeds (i.e., 27 $m\cdot min^{-1}$). Also, the StepWatch counted 1367 and 1843 more steps over the 24-hour period when compared to the SW-701 (spring-levered) and NL-2000 (piezoelectric), respectively. For non-ambulatory steps, the StepWatch will count each revolution of a cycle ergometer and nearly every leg swing. However, the StepWatch did not count any steps during car driving and only ~25% of heel tapping. The authors concluded that the StepWatch could be used as a criterion device because of its ability to accurately measure walking steps, even while walking slowly. Additionally, they suggested that the added steps from non-ambulatory activities would contribute very little to the total step count over a 24-h period.

The ability of ankle-mounted step counters (i.e., StepWatch) to accurately count steps at slow walking speeds while being unaffected by adiposity gives them a distinct advantage over waist-mounted devices, regardless of mechanism. Waist-mounted devices often fail to count steps taken during light intensity ambulatory activities, such as steps accumulated during housework (cooking and light cleaning) or light intensity office work. Researchers need to have the ability to accurately quantify all steps (light-vigorous) in order to examine possible associations with diseases related to light activity and sedentary behavior.

The volume of literature regarding the utility of using pedometers in children and youth is rather small when compared to the adults. However, as in adults, the Digi-Walker has been the most common pedometer used in research. Few studies have compared spring-levered and piezoelectric mechanisms or the effect of adiposity on the accuracy of pedometer counts in children. Because children and youth have different PA patterns compared to adults (children and youth are more sporadic), it should not be assumed that pedometers work the same in each group. In addition, children and youth are still maturing and my not have the mass to produce similar accelerations at the hip as in adults.

The accuracy of the Digi-Walker in children is relatively similar to adults in both laboratory-based and free-living research. For example, Ramirez-Marrero and colleagues (173) evaluated the Digi-Walker during various treadmill waking speeds in 7-12 year old African-American children. Similar to adult studies, the Digi-Walker significantly undercounted steps by nearly 13% when walking 3.5 $km \cdot h^{-1}$. The Digi-Walker has also been evaluated in the free-living environment. Barfield and colleagues (15) examined the inter-instrument consistency of the Digi-Walker in elementary school children by measuring total steps over one week of in-school activity. The researchers concluded the Digi-Walker was reliable in elementary school aged children, having an ICC of 0.94, 0.98, and 0.92 for classroom time, recess time, and PE time, respectively.

Nakae and colleagues (157) evaluated the accuracy of spring-levered (Yamax EC-200) and piezoelectric pedometers (Kenz and Omron HJ700IT) in primary school Japanese children (7-12 y) during self-paced walking. The children performed bouts while walking normally, slowly, and fast. The spring-levered device undercounted more than the piezoelectric device at all walking speeds. More specifically, the spring-levered device undercounted by at least 25% in all grades at the slow pace and the piezoelectric devices were within ±3% at the normal pace. Interestingly at normal walking pace, the spring-levered device was more accurate in children who were heavier. Once the body mass was $\geq$35 kg the error leveled off at ~10% for the spring-levered devices, however, the piezoelectric devices remained steady at ~3% error regardless of body mass. This decreased accuracy of the spring-levered device with lower body mass was also seen in preschool children (167). This could be partially due to between instrument differences in sensitivity to register a step. The authors concluded that spring-levered devices should not be recommended for measuring steps in children. Instead, piezoelectric devices are preferred.

The effect of adiposity on pedometer accuracy in children is unclear. Abel and colleagues (8) examined the accuracy of the Yamax SW-701 in children 9-15 years of age with high (89.2 ±9.5 cm) and low (60.6 ± 4.4 cm) WC groups. Pedometers were placed on the waist anterior in line with the thigh, posterior in line with the thigh, and in the mid-axillary line. Participants walked on a treadmill at 59, 72, and 86 m$\cdot$min^{-1} and a 400-meter self-paced walking trial over ground. This study found that there were no differences among the different pedometer locations for the low WC group. However, the posterior placement improved the accuracy of the pedometer in children with a high WC at each treadmill speed and self-paced walking. This study concluded that high abdominal adiposity (high WC) can lead to increased pedometer tilt and decreased pedometer accuracy. However, the practicality of placing the pedometer in a posterior position is still unclear. Graser and colleagues (94) examined the effects of pedometer placement, use of a belt, and weight classification in seventy-seven 10-12 year old children while walking on a treadmill 80 m$\cdot$min^{-1}. The pedometer placements were on the waist in line with the navel, anterior midline of the thigh, posterior midline of the thigh, middle of the back, and right side. The authors found that the use of a belt improved the accuracy of the pedometer (Walk4Life LS 2505) only in the normal weight group and that the right side placement was recommended due to the ease of reading the pedometer. Duncan et al. (60) found that BMI and percent fat did not affect the accuracy of the NL-2000 (piezoelectric) or the Digi-Walker SW-200 (spring-lever) in children (5-7 and 9-11 y.o.) while walking on a treadmill. However, the authors did conclude that pedometers showed significantly more bias as the tilt angles (>10°) increased, and that the NL-2000 showed similar accuracy and better precision than the SW-200. The authors determined that the NL-2000 is a better choice than the SW-200 for measuring steps in children. Mitre and colleagues (153) examined pedometer accuracy in normal weight and overweight or obese children (11 ± 1 y) while walking on a treadmill at 0.5, 1.0, 1.5, and 2.0 mph. Two spring-levered pedometers (Digi-Walker SW-200 Omron HJ-105) were used along with the ankle-mounted StepWatch. The authors mistakenly describe the Omron HJ-105 as a "piezoelectric" device, however, this is actually a spring-levered device (personal communication with Shariq Khan, Omron Inc., October 2, 2009). The StepWatch was more accurate, compared to the waist-mounted pedometers. The StepWatch recorded an average of 76%, 95%, 96%, and 98% of actual steps at the respective walking speeds. Interestingly, the waist-mounted pedometers performed similarly to each other, missing nearly 100% of the steps at the slowest speed and ~60% of the steps at the fastest speed (2 mph). Additionally, both devices undercounted more in the overweight group when compared to the normal weight group. As in previous studies, the StepWatch was very accurate, regardless of BMI status. One limitation of this study was that they had an insufficient number of subjects to analyze the data between normal, overweight, and obese groups. Therefore, they combined the overweight and obese groups. Based on this study, it is important to note that because waist-mounted devices may undercount more with greater BMI, studies indicating decreased walking volume with greater BMI in children should be interpreted with caution until the magnitude of the error is better understood (9).

Because the StepWatch is extremely accurate regardless of adiposity or walking speed in adults, it is important to understand and evaluate the utility of the StepWatch in children and youth. McDonald and colleagues (147) examined this topic in 97 children and youth (6-20 y). During 10 minutes of self-paced walking, the StepWatch had an accuracy of 99.87% when compared to manually counted steps. The researchers concluded that the StepWatch is an accurate and useful tool to assess walking volume in children and adolescents during activities in the free-living environment.

The pedometer has become a valuable, low cost tool to objectively measure ambulatory activity. The pedometer is noninvasive and easy to use. The limitations of the pedometer include the inability to be worn during swimming activities, inability to determine the patterns of PA (including intensity, frequency, & duration), and they cannot measure upper-body work (i.e., carrying an object). Additionally, there are mixed data regarding the effects of adiposity on the accuracy of pedometers worn on the waist. As our knowledge and technology continue to improve, many of these limitations can be overcome.

Accelerometers

Accelerometers have been used for approximately 35 years, with one of the first to measure PA described by Laporte and colleagues (121) in the late 1970's. Accelerometers measure acceleration, or change in velocity over time, which is expressed in terms of gravitational force ($g=9.8\ m^{.}s^{-2}$) and typically have a sampling rate of 10-30 Hz. Early accelerometers did not appear to be very promising. Montoye and et al. (155) suggested in 1996 that "these instruments have no direct application to the measurement of habitual PA in the field." However, for many researchers validation studies using DLW (27) and the development of regression equations to estimate EE (48) have made accelerometers instruments of choice to objectively measure PA. For example, accelerometers are now being used as part of NHANES to objectively measure PA of Americans (212) and to validate PA questionnaires such as the IPAQ (46). Advances in technology have made it possible for accelerometers to measure PA in one or multiple planes. Theoretically, accelerometers that use multiple planes are more accurate. However, the data are still inconclusive regarding their increased accuracy (84).

Accelerometers have several advantages including; objective measurement of PA occurring in real time, small and light weight, measures intensity and duration, noninvasive, can measure steps, and they have the ability to store data for many days. Another key advantage of using accelerometers is that they can evaluate both quality and quantity of PA (84). Some limitations of using accelerometers include; inability to assess water-based and upper body activities, can involve complicated equations to convert to EE, expensive (typically about $400), and the output may be influenced by device placement (concern during prolonged assessment of PA). Another significant limitation of using accelerometers is that manufacturers do not define a "count" similarly. There have been numerous accelerometers reported in the literature including the Actigraph, Actical, Caltrac, TriTrac-R3D, and RT3 Research Tracker. In general, a greater number of counts per unit of time (i.e., 1 second-60 second EPOCHs) are recorded as the intensity of physical activity increases. Therefore, researchers need to develop specific regression equations based on measured oxygen consumption (indirect calorimetry) for each accelerometer device for both adults and children. Regression equations are not necessarily accurate across the wide range of physical activities that can be performed. It is especially challenging to develop regression equations for children due to growth, maturation, and their sporadic pattern of PA.

The Actigraph is one of the most commonly used accelerometers in research (48, 50, 84, 212). There have been several versions of the Actigraph device including the 7164, three different versions of the GT1M, and most recently the GT3X. Researchers should not assume that different versions of the same device work the same. Therefore, research is done to determine if output from the different versions of Actigraph are similar (108). This helps to determine if studies utilizing different versions of the same device can be compared. This is especially important in accelerometer research because the technology is constantly changing. Numerous regression equations have been developed for adults that can estimate EE for treadmill running (85), treadmill walking (85, 128), over ground running (30), over ground walking (200), and numerous lifestyle activities (49, 50, 200). There are typically larger variations of successive accelerometer counts while performing lifestyle activities (i.e., vacuuming, sweeping, and tennis) when compared to walking activities (36). With few exceptions, equations developed on the treadmill or over ground walking or running tend to overestimate light and sedentary activity, give reasonable estimations for slow and fast walking, and underestimate all other activities (48). However, equations developed on lifestyle activities tend to overestimate sedentary and light activities and slow and fast walking, overestimate PA >6 METs, and provide reasonable estimations of EE at intensities between 3 and 6 METs (48). In most cases, regression equations work well while performing the activity they were developed on, while they do not perform well across a wide range of different activities and intensities, or the free-living environment (48).

One method used to improve EE prediction is to use a 2-regression model (49). Using the Actigraph, researchers found that walking and running activities had less variability in activity counts when compared to free-living activities (i.e., vacuuming, sweeping, and raking leaves). With this method, variability between counts was addressed by using a 10-s EPOCH and two regression equations to differentiate between walking/running from all other activities. Additionally, regression equations used to estimate EE during walking/running and moderate intensity lifestyle activities had differing slopes, which further demonstrated the need to use this approach. This allowed the prediction of EE to be within 0.75 METS, which was a significant improvement from using a one regression equation (49).

The most commonly used regression equations for the Actigraph in children performing walking and running activities come from Trost et al. (213) and Freedson and colleagues (85). Pyuru and colleagues (171) validated and calibrated the Actigraph in children performing various activities (i.e., playing video games, walking, jogging, skipping rope, etc.) using a room respiration calorimeter. Equations have also been developed during a variety of activities frequently performed by children such as walking, running, playing catch, hop-scotch, and coloring with crayons (73) and even at different intensities to determine accelerometer count thresholds (211). Activity counts in children have proven to have large variability when attempting to determine the relationship with EE, which can lead to large errors in predicting EE (66, 84, 148). Even during walking activities the coefficients of variation can be 21-40% per minute at a given velocity (66). This has limited developments of multiple regression models to more accurately estimate EE in children. Therefore, Ekelund and colleagues (67) established accelerometer count cut points in 500-counts-per-minute increments to define sedentary-vigorous activities. Defining these cut points also allows further examination of associations between intensity of PA and various health variables.

The utility of accelerometers to objectively assess PA has come a long way. Further development of these devices along with more precise regression equations will lead to a more accurate assessment of PA. Standardizing the definition of a “count” could prove to be valuable in developing regression equations. This would allow for researchers to apply regression equations between manufacturers.

Heart Rate Monitoring

Heart rate monitoring (HRM) can be a very beneficial way to estimate PA because it uses an easily measured physiological variable. HRM allows for researchers to determine the intensity, duration, and frequency of PA with relatively good association with EE. During consistent moderate-vigorous activity, heart rate (HR) increases linearly in relation to oxygen consumption and is highly correlated. The correlation during sedentary-light intensity activities is relatively poor and can be greatly influenced by factors other than PA such as temperature, emotions, and hormone levels (70, 136). Therefore, because of the variability of the relationship between HR and oxygen consumption, several methods have been introduced to help reduce the error associated with estimating free-living EE from HRM. Some of these methods include percent HRR, average net HR, and the Flex HR. One of the most popular is the Flex HR.

Flex HR is one of the most commonly used approaches to estimate EE in the free-living environment (225 K. F. in ch 9 and Starling, R.D. in ch 12 #2587). This is a very complicated procedure that requires individual calibration to determine the relationship between HR and oxygen consumption. In order for Flex HR to work correctly, the relationship between resting HR and oxygen consumption are typically established while lying, standing, and sitting. Additionally, the relationship between HR and oxygen consumption during various intensities of exercise are needed. Flex HR is the average of the greatest HR during rest and the lowest HR during light exercise. Because heart rates below the Flex HR are poorly correlated with oxygen consumption, BMR is typically used during time spent sleeping (35).

Ceesay and colleagues (35) validated Flex HR using indirect whole-body calorimetry in 20 adults. The exercise modalities used to determine the relationship between HR and oxygen consumption were cycle ergometry at workloads of 25, 50, and

75 watts and stepping at 20 steps$\cdot$min^{-1} on a 225 mm block with five minutes of rest between bouts. Next, the participants spent 21.5 hours in a room calorimeter and exercised on a cycle ergometer at 50 watts, rowed at 20 strokes$\cdot$min^{-1}, and jogged in place at 138 steps$\cdot$min^{-1}. The Flex HR method underestimated TEE by 1.2% ±6.2% (range -11.4 to 10.6%). It is important to note that of the 21.5 hours of measurement only an average of 98 minutes were spent above Flex HR, which is equivalent to only ~7.5% of the measured time. The rest of the time spent outside of the Flex HR range was estimated.

Livingstone and colleagues (136) compared Flex HR to DLW in 36 children/adolescents (19 boys, 17 girls) 7-15 years of age. Calibration curves were developed using supine, sitting quietly, standing quietly, and exercising on a treadmill at 2.7 km$\cdot$h^{-1} at a 10% grade and 4.0 km$\cdot$h^{-1} at a 12% grade. Because many of the children had high standing heart rates (many significantly higher than the low intensity exercise on a treadmill), the mean of all of the resting heart rates were averaged. This was probably driven by psychological variables (they were nervous). The subjects were then monitored for 2-3 days to compare Flex HR and DLW. Flex HR TEE was relatively close to DLW, ranging from -16.7% to 18.8%, with 23 of the 36 values within ±10%. In a previous study using adults, Livingstone and colleagues (137) found similar results only with a wider range, -22.2% to 52.1%.

Because of the complicated process of Flex HR and the sporadic nature of children's PA, Livingstone and colleagues (138) tested different calibration methods using various body positions and movements to estimate free-living TEE by Flex HR in seven young males (8-10 y). The results showed no significant differences in TEE estimates among the seven different Flex HR methods. Their results suggest that more complicated and elaborate calibration equations do not lead to more accurate estimates of TEE. Also, the more sedentary the children, the more likely the complicated calibration procedures would not be justified (138). Furthermore, researchers suggest that this observation would also apply to adults (225 K. F. in ch 9 and Starling, R.D. in ch 12 #2587).

Because HR is a physiological variable, the Flex HR method can be very beneficial to monitor PA. However, the labor-intensive individual calibration procedures and relatively high participant burden could be too much for most research questions. In addition, many researchers have found that this method is highly variable, not necessarily accurate, and show mixed results in both adults and children (136-138, 195)

Summary

The importance of PA is clear. Our ancestors were required to be physically active based on their daily lifestyle. The modern conveniences (automobiles, washing machines, television, etc.) we enjoy today have allowed, even encouraged, us to develop a sedentary lifestyle. PA has the potential to attenuate many hypokinetic associated diseases and syndromes (diabetes, obesity, metabolic syndrome). Because our ability to recall physical activity is poor, especially with light PA, it is important to understand and objectively quantify the amount of PA we are doing (or not doing). Additionally, objective monitors of PA need to be accurate regardless of adiposity (i.e., BMI or WC), body size (adult or child), or intensity of the activity (i.e., waking and running).

Therefore, the scientific community needs to continue to develop and test objective monitors of PA so that we may better understand/quantify PA. We must accurately assess the quantity and quality of PA in order to accurately describe the relationship between PA and health-related outcomes.

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Part III

Effects of BMI and Step Rate on Pedometer Error In a Free-Living Environment

This part is a paper by the same name that will be published in *Medicine and Science in Sports and Exercise* in 2010 by Brian Matthew Tyo, Dinesh John, Yuri Feito, Eugene Fitzhugh, David Bassett, Jr., and Dixie Thompson

Tyo B, Feito Y, Fitzhugh E, Basett DJ, John D, and Thompson D. The Effects of BMI and Step Rate on Pedometer Error In a Free-Living Environment. *Med Sci Sports Exerc*. In Press.

Abstract

Pedometers could provide great insights into walking habits, if they are found to be accurate for people of all weight categories. **Purpose:** To determine if the New Lifestyles NL-2000 (NL) and the Digi-Walker SW-200 (DW) yield similar daily step counts as compared to the StepWatch 3 (SW) in a free-living environment and to determine if pedometer error is influenced by BMI and speed of walking. The SW served as the criterion, due to its accuracy across a range of speeds and BMI categories. Slow walking was defined as ≤80 steps per minute. **Methods:** Fifty-six adults (32.7 ± 14.5 y) wore the devices for seven days. There were 20 normal weight, 18 overweight, and 18 obese participants. A two-way repeated measures ANOVA was performed to determine if BMI and device were related to number of steps counted per day. Stepwise linear regressions were performed to determine what variables contributed to NL and DW error. **Results:** Both the NL and DW recorded fewer steps than the SW ($P<0.001$). In the normal weight and overweight groups, error was similar for the DW and NL. In the obese group, the DW underestimated steps more than the NL ($P<0.01$). DW error was positively related to BMI and percentage of slow steps, while NL error was linearly related to percentage of slow steps. A surprising finding was that many healthy, community-dwelling adults accumulated a large percentage of steps through slow walking. **Conclusion:** The NL is more accurate than the DW for obese individuals, and neither pedometer is accurate for people who walk slowly. Researchers and practitioners must weigh the strengths and limitations of step counters, before making an informed decision about which device to use.

Introduction

Pedometers have been used in many studies as objective monitors of physical activity (3, 11, 16, 21, 22, 25, 26). Studies using pedometers have shown inverse relationships between measured steps and indicators of adiposity (10, 15, 16, 26, 28, 30). However, there are conflicting data on the effect of body mass index (BMI) and stepping rate on the accuracy of waist-mounted pedometers (3, 13, 21, 22, 25). The development of devices to measure walking is particularly important because walking is one of the most popular forms of leisure-time physical activity and the ability to recall walking on surveys is questionable, especially when compared to more vigorous activity (1, 8, 33). Pedometers have great potential for use in intervention and observational studies, if they are found to be accurate for all individuals.

There are many types of pedometers on the market today commonly used for research. Previous studies have suggested that some pedometers are more valid and reliable than others (3, 4, 13, 21, 22). Evidence from laboratory-based validation studies has shown that variables such as BMI, waist circumference (WC), and stepping rate could impact accuracy (3, 18, 21, 23). Additionally, there is evidence that certain mechanisms used by waist-mounted pedometers, such as the New Lifestyles NL-2000 (NL) and the Digi-Walker SW-200 (DW), could contribute to these inaccuracies (3). The NL has a piezoelectric mechanism while the DW utilizes a spring-suspended horizontal lever arm (3). Irrespective of body size, the NL has been found to be accurate and reliable at various walking speeds on a treadmill (54-107 $m \cdot min^{-1}$) and walking on a track at a self-selected speed (3, 4, 17, 21, 22). However, the NL accuracy diminishes at speeds below 54 m$\cdot$min^{-1}, when compared to a criterion measure (13). The DW has been used in normal, overweight, and obese populations under various walking conditions in the lab and free-living environment (2, 3, 21, 25, 26). In the lab, the DW has been shown to significantly underestimate steps taken at slow walking speeds ($\leq$ 94 m$\cdot$min^{-1}), while being highly accurate at fast speeds (> 94 m$\cdot$min^{-1}) and during self-selected walking speeds (3, 13, 22, 25). In addition, there have been conflicting reports on whether a high BMI decreases the accuracy of the DW (3, 25). It is important to identify factors that contribute to error in these devices.

Another type of step counter is the StepWatch, an ankle-mounted, dual axis accelerometer-based pedometer. It has the ability to measure step rate for each minute of a 24-hour period over multiple days, while classifying each minute into low, medium, and high step rates. A study using a previous version of the StepWatch showed that it is very accurate for measuring steps across a wide range of speeds, and that it is not affected by BMI (23). The newest version of the StepWatch, StepWatch 3 (SW), is more accurate than waist-mounted pedometers for measuring treadmill walking (26.8-107.3 m$\cdot$min^{-1}), especially at the slower walking speeds (13). Additionally, the SW yields extremely accurate step counts during slow hallway walking (7, 13), and it is considered the instrument of choice for measuring very slow gait speeds (<48 m$\cdot$min^{-1}) (24). One study found that the SW gave a mean step count within 1% of manually counted steps at various walking speeds on a treadmill and suggests that it could be used as the criterion to validate waist-mounted pedometers (13). Since people walk at various speeds under free-living conditions, the SW appears to be a good choice as a criterion device.

It is important to examine the accuracy of waist-mounted pedometers in the free-living environment, using a criterion that is unaffected by obesity or speed of walking. Therefore, the purpose of this study was to determine if the NL and DW yield similar step counts compared to the SW in a 7-day free-living environment. A secondary purpose of this study was to determine if errors in step counting are related to BMI and/or speed of walking.

Methods

Participants

The experimental protocol and informed consent form were approved by the University of Tennessee Institutional Review Board. Individuals between 18 and 66 years of age were eligible to participate in this study. Potential subjects were excluded if they had an internal defibrillator or pacemaker, were pregnant, had difficulty walking, and/or used a cane or other device for ambulatory movement. Participants were recruited through flyers, internet postings, and word of mouth. Prior to data collection, each subject provided informed consent to participate in this study.

Seventy people participated in the study. However, at the end of the study, 14 participants were excluded for a variety of reasons including: incomplete pedometer data on two or more days, bicycling on two or more days, elliptical training on two or more days, and/or having a BMI ≥ 40 $kg \cdot m^{-2}$. As a result, 56 participants were included in the final statistical analysis.

Measurements

Participants met with investigators on two separate days, eight days apart, with pedometers being worn for seven consecutive days. For instance, if the first meeting occurred on a Monday, the second meeting would be the following Tuesday. For the initial visit, participants were asked to wear light clothing (shorts and T-shirt) and avoid eating and exercising four hours prior to visiting the laboratory. After removing shoes and socks, participant height was measured using a stadiometer and weight was measured using either a calibrated scale (7 subjects) or the Tanita BC-418 (Tanita Corp., Tokyo, Japan) (49 subjects). The calibrated scale was used on seven subjects because these participants could not attend an appointment in the lab and it was not feasible to transport the Tanita BC-418. Participant waist (WC) and hip circumferences (HC) were measured standing with the feet together using a measuring tape with a tension handle (Creative Health Products, Inc., Plymouth, MI). WC was measured at the end of a normal expiration at the narrowest portion of the torso, between the bottom of the xiphoid process and the umbilicus. HC was measured at the greatest circumference of the buttocks. Measurements were made in duplicate and repeated if values differed by more than 5 mm and the two closest values were then averaged to obtain the final measure. Waist-to-Hip Ratio (WHR) was calculated by dividing WC by HC. BMI was calculated by dividing weight (kg) by height (m) squared. Subjects were then classified into standard BMI categories: normal weight (18.5-24.9 $kg \cdot m^{-2}$), overweight (25-29.9 $kg \cdot m^{-2}$), and obese (≥ 30 $kg \cdot m^{-2}$).

After anthropometric measurements were made, participants were instructed on how to wear the activity monitors. The SW was used as the criterion and was worn on the right ankle just above the lateral malleolus (7). Since the SW counts the steps taken with only one foot, the values were multiplied by two to determine the total steps per day. Additionally, the SW can classify the stepping rate for each minute into low (<30 steps per minute), medium (30-80 steps per minute) and high (>80 steps per minute) categories. The number of steps in the low and medium step-rate categories were summed and divided by the total number of steps per day to determine the slow step-rate percentage for each day. A step rate of 80 steps per minute is approximately equal to walking 40.2 $m \cdot min^{-1}$ (1.5 mph) for a person 177.8 cm (70 inches).

The NL was sealed using a plastic cable tie and was worn on the left side of the waist at the midline of the thigh. The DW was worn on the right side of the waist at the midline of the thigh (26). Participants were instructed to wear the pedometers during all waking hours except when bathing. Participants were discouraged from performing non-ambulatory activities such as biking and elliptical training. Each morning, the DW was reset to zero by the participant and each evening the participants recorded their step value for the day before going to bed. After seven days of continuous monitoring, the devices and daily step count records were returned to the investigator during the follow-up visit to the laboratory. Ten participants bicycled or had missing data for one of the seven days. Research has shown that step counts accumulated on a weekday differ from the step counts accumulated on a weekend day (1, 32). For participants who bicycled or had missing data on a weekday (N=7), data were imputed by averaging the 4 remaining weekdays. For those subjects missing a Saturday (N=3), the missing data were imputed by taking the average of the remaining six days (1). The missing days accounted for less than 2.6% of the total days (10 days x 56 participants).

Statistical Analyses

One-way ANOVAs were conducted to determine differences among BMI categories, for each of the following variables: age, height, weight, WC, HC, and WHR. Next, 3 x 3 two-way repeated measures ANOVA was performed to determine if BMI and device influenced steps per day. Where appropriate, pairwise comparisons with Bonferroni adjustment were performed to locate differences among the devices within each BMI category. A one-way ANOVA was used to determine if there were differences among the BMI categories in steps per day, for each device. Where appropriate, Tukey HSD post hoc analyses were used to determine which BMI categories differed from each other for each device. The error (error = [(pedometer steps per day– criterion pedometer steps per day) / criterion pedometer steps per day] x 100) was calculated for the NL and DW. One-way ANOVAs were performed to examine differences in error between BMI categories for the NL and DW. Tukey HSD post hoc analyses were used to determine which BMI categories differed from each other, for each device. A paired samples t-test was performed to determine if error was significantly different between the DW and NL within each BMI category. Pearson's bivariate correlation coefficients were calculated to determine the relationships between the error of the waist-mounted pedometers and slow step-rate percent, BMI, WC, HC, and WHR. Finally, stepwise linear regressions were then performed to determine if BMI, slow step-rate percent, WC, and HC contribute to NL and DW error. Analyses were carried out using SPSS 17.0 (SPSS Inc., Chicago, IL), and the alpha level was set at 0.05 to indicate statistical significance.

Results

Participant characteristics are shown in Table A-1 (pg. 153). The obese group was significantly older and had a higher WHR than both the normal weight and overweight groups ($P<0.05$). All BMI categories were significantly different for weight, BMI, WC, and HC.

Mean error with 95% confidence intervals are presented in Table A-2 (pg. 154). Repeated measures ANOVA revealed significant device by BMI interaction [$F(4,52) = 3.832$, $P < 0.01$]. The SW counted significantly more steps than both the NL and DW within each BMI category ($P < 0.001$) and the NL counted significantly more steps than the DW for the obese BMI category ($P < 0.05$). This can be seen in Figure A-1 (pg 159).

Table A-2 (160) shows the error of the NL and DW for each BMI category. The DW error differed among BMI categories [$F(2, 54)= 9.359$, $P < 0.001$)] while the NL error showed no significant differences. It can be seen that the DW underestimated steps for the obese group to a greater extent, compared to the normal and overweight groups ($P < 0.01$). Additionally, the DW error was significantly greater than the NL error for the obese group ($P < 0.05$).

Pearson correlations (Table A-3, pg. 155) revealed that the NL error was significantly correlated with slow step rate percent and HC, while the DW error was significantly correlated with low step rate percent, BMI, HC, and WC. Thus, stepwise regression analysis was performed to determine what combination or variables most significantly contribute to the error of the NL and DW. The DW error was related to BMI and slow step rate percent, but the NL error was related to only slow step rate percent. This analysis revealed that 51.1% of the variance in the DW error ($R^2 = 0.511$, SEE = 10.6, $P < 0.001$) was explained by the combination of stepping frequency ($\beta=-0.476$) and BMI ($\beta=-0.421$) and that 43.3% of the variance in the NL error ($R^2 = 0.433$, SEE = 9.2, $\beta=-.658$, $P < 0.001$) was explained solely by stepping frequency.

Figure A-2A (pg. 160) shows the correlation between slow step rate percentage and DW error, while Figure A-2B (pg. 160) shows the relationship between BMI and DW error. Figure A-2C (pg. 160) shows the relationship between slow step rate percentage and NL error, while figure A-2D (pg. 160) shows the relationship between BMI and NL error. Figure A-2 (pg. 160) also shows 95% confidence and prediction intervals. A confidence interval is typically described as a forecast interval for the mean, and a prediction interval is a forecast interval for an individual value (20).

Discussion

To our knowledge, this is the first study to use the SW as a criterion to evaluate the NL and DW in normal weight, overweight, and obese adults in free-living conditions. The major findings of the present study are: 1) The SW recorded significantly more steps than the DW and NL regardless of BMI category, 2) the DW and the NL errors were similar for the normal weight and overweight groups, but the DW had greater error than the NL in the obese group, 3) DW error increased as the percentage of slow steps and/or BMI increased, and 4) the NL error increased as the percentage of slow steps increased. In addition, the SW recorded 15-33% more steps than the DW or NL, showing that data collected with the SW should not be directly compared to previous studies using those waist-mounted devices nor compare SW data to step indices based on the DW (31).

Comparisons of the steps per day for each device

Studies using spring-levered pedometers have suggested that the number of steps per day is lower in individuals with higher BMI (26, 33). In addition, several studies using a spring-levered pedometer have shown an inverse relationship between daily steps and BMI (10, 26, 30, 33). Part of the difference in daily walking volumes between BMI categories reported in previous studies may be attributable to the undercounting of steps in obese subjects, when using a spring-levered pedometer (3).

Digi-Walker error

Our results suggest that when using the DW, the error will be greater in individuals with a high BMI and in individuals who walk slowly. This relationship is best described in Figure A-2 (A&B, pg. 160), which shows the correlation of pedometer error with SSRP and BMI. The DW has greater error with increasing BMI and also has greater error with increasing slow step rate percent. This is in agreement with previous laboratory-based research, and it is due to the fact that slow walking does not generate sufficient accelerations at the hip to exceed the “threshold” needed for step recording. Melanson et al. (18) showed that DW error was inversely related to walking speeds and positively related to BMI. Karabulut et al. (13) also found that waist-mounted pedometers have more error at slower speeds (i.e. 27 m·min^{-1}). Crouter et al. (3) found that tilt angle, BMI, and WC contributed to the DW error. Tilt angle was not used in the current study because the tilt angle is highly dependent on how the pedometer is worn and can vary daily depending on the type of clothing to which the pedometer is attached. In the current study, the normal weight, overweight, and obese groups took 62.1%, 63.5%, and 70.3% of their steps at a slow stepping rate, respectively. Although not significantly different, the obese group tended to take more of their steps at a slower rate, which likely contributed to the increased error seen in this group.

The current finding that stepping frequency and BMI contribute to DW error has implications for interpreting studies that have used spring-levered devices to describe the relationship between adiposity and walking volume (10, 26, 31, 33, 35). For instance, Tudor-Locke et al. (33) and Wyatt et al. (35) found differences of 2,411 and 2,392 steps per day, respectively, when comparing normal weight and obese groups. According to the present study, almost 50% of these differences can be linked to the aforementioned limitations of the DW. Hornbuckle et al. (10) and Thompson et al. (26) also reported inverse associations between BMI and daily step volume. It would be desirable to re-examine the findings of these studies that have used spring-levered pedometers, using a device that is not influenced by BMI or stepping rate, such as the SW.

NL-2000 error

Slow walking, and not BMI, was found to contribute to NL error. This relationship is best described in Figure A-2C and 2D (pg. 160). The NL has greater error with increasing slow step rate percent. However, the NL error is not influenced by BMI.

This finding is in agreement with the laboratory studies of Crouter et al. (3), who showed that the accuracy of the NL was unaffected by BMI and tilt angle. Additionally, the current study concurs with the findings of Karabulut and colleagues (13) who showed that slow walking speeds can influence the accuracy of the NL. In the current study, there was no significant difference between the NL and DW errors for the normal weight and overweight groups. However, the DW had significantly more error compared to the NL for the obese group.

Piezoelectric vs. spring-lever mechanism

The DW is a spring-levered pedometer that has a threshold of 0.35 G to record a step (29). The NL utilizes a piezoelectric mechanism and the threshold is considered proprietary. Piezoelectric accelerometers, such as the Actigraph 7164, commonly use a sensitivity of 0.30 G to detect a step (29). It has previously been suggested (18) that the difference in the sensitivity of the mechanisms may contribute to the discrepancies among waist-mounted pedometers. Additionally, spring-levered pedometers, such as the DW, are affected by tilt angle, while the piezoelectric mechanism of the NL does not have the same limitation (3).

Additional factors that could affect pedometer error

The current study demonstrates that BMI and/or step rate can contribute to waist-mounted pedometer error in the free-living environment. However, there are other factors that could contribute to the error of these devices. For example, people wear different styles of pants positioned in various ways on the hips or abdomen. In addition, body shapes can change how the pedometers are positioned. To date, no one has been able to quantify how much these variables contribute to the error of these devices.

Do All Steps Count?

Ironically, the current definition of a step centers around accelerations that are recorded at the hip. Typically, waist-mounted pedometers have thresholds 0.30-0.35 g needed to trigger a step. More movement occurs at the foot than the waist, possibly making it easier to detect a step with an ankle mounted device. The principle of operation for the StepWatch is not known because it is proprietary information. However, this device is very accurate for recording steps even with slow stepping rates indicative of light-intensity physical activity. We understand the view of some researchers who suggest that those steps should not be recorded, because they are not at a moderate intensity or above. Some have also suggested that devices that record very light-intensity or intermittent steps should be adjusted so as to remove these steps (34). However, our view is that all steps may be worth recording. This is based partly on recent research demonstrating the health hazards of too much sitting (i.e., sedentary behavior). This research has shown that sedentary behavior is associated with increased all-cause mortality, CVD, BMI, and fasting insulin levels (6, 14, 27). Moreover, one study showed that amount of time spent in sedentary and light-intensity activities were inversely correlated (r=-0.96). This suggests that there could be metabolic benefits to substituting light-intensity activity for sedentary time (9).

Strengths and limitations

A strength of the present study was the use of a criterion pedometer, which allowed us to compare the accuracy of piezoelectric (NL) and spring-lever (DW) pedometers in a free-living environment over a 7-day period. However, this study also has limitations. For instance, the SW (an ankle-mounted pedometer) is vulnerable to extraneous movements such as heel tapping and leg swinging, but not car driving (13). However, Karabulut and colleagues (13) suggest that such movements would not make a meaningful contribution to the total number of steps over a 24-hour period. Furthermore, Orendurff and colleagues (19) report that repeated shaking of the foot will not cause additional counts due to a step-detection algorithm. We also considered the possibility that low step frequencies (below 80 steps per minute) did not represent slow walking, but rather represented normal-paced walking bouts that started and/or stopped part way through a minute. However, we rejected this notion because we observed strong relationships between the percentage of slow steps and pedometer accuracy. The only plausible explanation for this is that certain people walked slowly and pedometers are known to under-count at slow speeds (<2 mph). If a person performed brief, intermittent walking bouts at a normal pace, both the DW and NL should have recorded all of the steps taken.

Summary

A surprising new finding was that some healthy, community dwelling adults accumulated a large percentage of steps through slow walking, and waist-mounted pedometers are inaccurate in this population. Slow walking was defined as $\leq$ 80 steps per minute, which is roughly equivalent to walking at 1.5 mph. This new finding extends previous research showing that waist-mounted pedometers are inaccurate in older adults in nursing homes (5) and assisted living facilities (2), due to their very slow gaits.

There are several practical applications to be discussed. Staying with the DW, a spring-levered device, allows researchers to draw comparisons with previous studies and analyze time trends. Due to its low cost, practitioners might also select the DW for use in health promotion settings. However, researchers should recognize the limitations of using a spring-lever device. Specifically, using the DW in an obese population will result in twice as much pedometer error (i.e. - undercounting) as that seen in a normal weight group. Because of this error, the DW is not appropriate for examining the relationship between step counts and adiposity. Second, the DW also undercounts steps in those who accumulate a large percentage of their total steps through slow walking (2, 5, 12). Therefore, if a researcher is interested in counting all steps, including those taken during slow walking, the SW would be a good choice. However, there are trade-offs when deciding whether to use a new technology. It is often more accurate, but the stability of measurement tool over time is sacrificed, and comparisons cannot be made with previous studies. Researchers and practitioners must weigh these trade-offs in selecting a device that suits their purpose.

In conclusion, researchers must bear in mind the limitations of any device being used to monitor daily ambulation. Waist-mounted pedometers are useful for intervention studies that seek to encourage participants to increase their walking. However, slow stepping rates and high BMI can negatively affect their performance.

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Part IV

The Effect of BMI on Waist-Mounted Pedometers Worn by Early Adolescents in a Free-Living Environment

Abstract

Pedometers provide valuable information regarding the ambulatory patterns of adolescents. Pedometers need to be accurate for all adolescents, regardless of BMI. **Purpose:** The purpose of this study was two-fold: (1) To determine if the New Lifestyles NL-2000 (NL) and the Digi-Walker SW-200 (DW) yield similar step counts as compared to an ankle-mounted criterion, StepWatch 3 (SW), when worn by early adolescents in a free-living environment and (2) to study whether BMI percentile, weight, and maturity offset affect the accuracy of waist-mounted pedometers in adolescents. **Methods:** Seventy-four early adolescents (13.0 ± 1.1 y) wore the devices during one weekday. There were 33 normal weight, 21 overweight, and 20 obese participants. Two-way repeated measures ANOVA determined if BMI and device were related to number of steps per day and percent of actual steps. Stepwise linear regressions examined which variables contributed to undercounting of the NL and DW. **Results:** The NL and DW recorded fewer steps than the SW in each BMI category (P<0.05). In the obese group, the DW underestimated steps more than the NL (P<0.001). For the normal weight, overweight, and obese groups, the NL counted 89.1%, 89.1%, and 91.6% of the steps, respectively, while the DW counted 86.7%, 84.6% and 72.7%, respectively. **Conclusion:** The NL has less error than the DW for obese adolescents. The DW should not be used to determine the relationship between adiposity and walking volume, nor should it be used to quantify steps in obese adolescents. The NL is better device for assessment of adolescents' steps.

Introduction

Pedometers have been commonly used in research as an objective measure of physical activity in both adults and children (3, 5). It is well established that waist-mounted pedometers undercount more at slow walking speeds (e.g., $\leq 54\ \mathrm{m \cdot min^{-1}}$) and that some devices are more accurate than others, particularly in obese individuals (2, 9, 14, 17, 18, 20). It is important to develop accurate objective measures of physical activity because the ability to recall physical activity is poor, especially in children (23).

An inverse relationship between physical activity (steps per day) and body mass index (BMI) has been reported in children (21, 28). As a result, criterion-referenced steps per day goals for children have been established based on percent fat and BMI (8, 26). However, it has not been established which pedometers are the most accurate for all people, regardless of adiposity or BMI status.

Pedometers commonly use piezoelectric and spring-lever arm mechanisms (6, 18). Studies have found that piezoelectric devices are more accurate than spring-levered devices (6, 9, 18). The data are mixed regarding the effects of BMI on the accuracy of spring-levered devices in adults (6, 10, 24, 27). For instance, Crouter and colleagues (6) found that the Digi-Walker SW-200, a spring-levered device, tended to undercount more with greater BMI, while the New Lifestyles NL-2000 (piezoelectric) was not affected by BMI in adults walking on a treadmill ($54\text{-}107\ \mathrm{m \cdot min^{-1}}$). Tyo et al. also found that the DW under counts more in obese adults when compared to the StepWatch 3 (SW) in a free-living environment (27). The NL was not affected by BMI (27). However, other studies have reported that the DW in not impacted by adiposity. For instance, Swartz and colleagues (24) found that BMI did not affect accuracy of the DW in adults during treadmill walking (54-107 $m \cdot min^{-1}$). Eisenbaumer and colleagues (10) also found that the Digi-Walker was not affected by BMI during self-paced walking.

The accuracy of these waist-mounted devices has also been examined in children during various lab-based studies. Nakae and colleagues (18) examined the accuracy of spring-levered (Digi-Walker EC-200) and piezoelectric pedometers (Kenz Lifecorder and Omron HJ-700IT) in Japanese children (7-12 y.o.) during over ground walking. They found that the spring-levered device was not suitable for use in children and the piezoelectric devices were preferred (18). Additionally, Duncan et al. (9) found that a piezoelectric pedometer (NL-2000) was more accurate than a spring-levered pedometer (Digi-Walker SW-200) in children (9-11 y) while walking on a treadmill. Mitre and colleagues (17) examined the accuracy of two waist-mounted spring-levered devices (Digi-Walker SW-200 and Omron HJ-105) and an ankle-mounted step counter (StepWatch) in normal and overweight/obese children (11 ± 1 y) while walking at various speeds on a treadmill (13.4-54 $m \cdot min^{-1}$). The waist-mounted pedometers undercounted, compared to the SW, across all speeds and had greater pedometer error, (undercounting) in the overweight/obese group compared to the normal weight group. This study agrees with previous research in adults (6). The SW was more accurate than the waist-mounted pedometers at every speed and was not affected by BMI, which is consistent with studies in adult populations (11, 22). Because previous studies have only compared the accuracy of spring-levered and piezoelectric pedometers in laboratory studies, we wanted to examine the accuracy of these devices in the free-living environment using a criterion device. Additionally, we wanted to determine if BMI affects the accuracy of the waist-mounted devices, when compared to a criterion that is not affected by BMI, in a free-living environment.

The SW is an ankle-mounted, dual axis accelerometer-based step counter that is extremely accurate at measuring steps across a wide range of walking speeds in adults and children and is not affected by BMI (11, 14, 17). Because of this accuracy, the SW has been suggested as a good criterion device to validate waist-mounted pedometers (11) and to assess physical activity in children (17). No study has compared waist-mounted and ankle-mounted pedometers worn by children in a free-living environment. Therefore, the purpose of this study was to determine if the spring levered DW pedometer and piezoelectric NL pedometer yield similar step counts compared to the SW in early adolescents during 24-hours in a free-living environment. A secondary purpose was to determine if variables such as BMI percentile, weight, or maturity offset contribute to the error of waist-mounted pedometers.

Methods

Participants

The experimental protocol, informed consent, and informed assent were approved by both the University of Tennessee and East Tennessee Children's Hospital Institutional Review Boards. Early adolescents, defined as 11-14 years of age (1), were eligible to participate in the study. None of the participants reported difficulty walking and/or use of an assistive device. Participants were recruited through flyers and word of mouth from the Boy Scouts of America, Girls Scouts of the USA, East Tennessee Children's Hospital Weight Management Clinic, and the surrounding community. Participants recruited from the Weight Management Clinic were asked to participate in the study prior to starting an exercise program.

Prior to data collection, participants and their parents/guardians met with investigators. The parent/guardian read and signed the informed consent. Participants were given the informed assent form and the researcher answered any questions. Those who agreed to participate either signed the assent form or gave verbal agreement to participate. Participants in the study included 84 early adolescents. However, at the end of the study 10 were excluded for several reasons including; inability to follow instructions, incomplete pedometer data, underweight (<5th percentile), and pedometer data considered "outliers" (i.e.- percent actual steps of waist-mounted pedometers >160% or <10% when compared to the SW). As a result, 74 participants were included in the statistical analysis.

Anthropometric Assessments

Height and weight were measured without shoes. Standing height was measured using a stadiometer (GPM Anthropometer). Seated height was measured using a stadiometer (GPM Anthropometer) while the participant was seated on a chair or table with a flat surface of sufficient height to allow the feet to hang freely and hands were placed on the thighs (13). Height was measured to the nearest 0.1 cm making sure the participant sat or stood as tall as possible with the head in the Frankfort Horizontal

Plane (13). Standing and seated heights were measured in order to calculate leg length, which was used along with gender, age, and weight to assess maturity offset (years from peak height velocity) as previously described by Mirwald and colleagues (16). Weight was measured using a calibrated digital scale to the nearest 0.05 kg (Lifesource Profit/IntelliSCALE). Participants were then classified into age and gender specific BMI categories; normal (5th-84.9th percentile), overweight (85th-94.9th percentile), and obese ($\geq$95th percentile) dependent on each individual's gender, height, and weight (12).

Devices

The researchers initialized the devices, by entering the participant characteristics. Each child's height was entered into the SW software and the box indicating "Quick Stepping" (e.g., "Child's Play") was selected. The time, height, and weight were entered into the NL and then sealed using a plastic cable tie. The participant, along with a parent/guardian, were then instructed on proper placement of the activity monitors. The SW was worn on the outside of the right ankle, just above the lateral malleolus. The waist-mounted pedometers were worn in line with the thigh on the right (DW) and left (NL) sides, with a safety strap attached to the clothing. The participants were asked to wear all of the pedometers simultaneously on a weekday during all waking hours except when bathing, or participating in activities that could damage the pedometers (e.g., soccer or football). Each participant was given an instruction sheet detailing the requirements for the measurement day. These instructions included pictures detailing the position of each device, a written explanation of the positions, a reminder to reset the DW to zero the morning of the measurement day, encouragement to accumulate at least 10 hours of wear time, and spaces to record wear time and DW steps. Participants were asked to refrain from performing non-ambulatory activities such as bicycle riding or using an elliptical machine. The researcher called the participants at the end of their measurement day to answer any questions. The devices and instruction sheet were mailed back to the researchers using a prepaid box. Each participant was given two movie tickets for volunteering time to participate in the study. Since the SW counts steps taken with one foot, the values were multiplied by two to determine the total number of steps per day.

Statistical Analysis

One-way ANOVAs were conducted to determine differences among BMI categories, for each of the following variables: age, height, weight, maturity offset, BMI, and BMI percentile. Next, 3 x 3 two-way repeated measures ANOVA was performed to determine if BMI and device influenced steps per day. Where appropriate, pairwise comparisons with Bonferroni adjustment were performed to locate differences among the devices within each BMI category. Next, one-way ANOVAs were used to determine if there were differences among the BMI categories in steps per day, for each device. Where appropriate, Tukey HSD post hoc analyses were used to determine which BMI categories differed from each other for each device. The percent of actual steps (pedometer steps per day/criterion steps per day) x 100) was calculated for the NL and DW. A 3 x 2 repeated measures ANOVA was used to determine if BMI and device influenced percent actual steps. Where appropriate, pairwise comparisons with Bonferroni adjustment were performed to locate differences between the devices within each BMI category. Next, one-way ANOVAs were performed to examine differences in percent of actual steps between BMI categories for both the NL and DW. Tukey HSD post hoc analyses were used to determine which BMI categories differed from each other, for each device. Pearson's bivariate correlation coefficients were calculated to determine the relationships between the percent actual steps of the waist-mounted pedometers and BMI percentile, maturity offset, and weight. Finally, stepwise linear regressions were performed to determine if BMI percentile, maturity offset, and weight contributed to the percent of actual steps for the NL and DW. Analyses were carried out using SPSS 17.0 (SPSS Inc., Chicago, IL), and the alpha level was set at 0.05 to indicate statistical significance.

Results

As previously described, ten participants were excluded, leaving a total of 74 participants included in the analysis. Participant characteristics are shown in Table B-1 (pg. 156). All BMI categories were significantly different for weight and BMI ($P<0.01$). The normal weight group was significantly different from the overweight and obese groups for BMI percentile ($P<0.001$). The obese group was significantly different from the normal weight for maturity offset ($P=0.01$).

A repeated measure ANOVA revealed a significant device by BMI interaction for steps per day [$F(4,70)= 3.821$, $P<0.01$]. The SW counted significantly more steps than both the NL and DW within each BMI category ($P<0.05$) and the NL counted significantly more steps than the DW for the obese group ($P<0.001$), which can be seen in Figure B-1 (pg. 161). Additionally, Figure B-1 (pg. 161) reveals that the DW counted fewer steps in the obese group when compared to the normal weight group ($P<0.05$)

Mean percent actual steps with 95% confidence intervals are presented in Table B-2 (pg. 157). Figure B-2 (pg. 162) shows the percentage of actual steps for the waist-mounted devices by BMI category. Repeated measures ANOVA revealed a significant device by BMI interaction for percent of actual steps [(4,70)=9.040, $P<0.001$]. Table B-2 (pg. 157) shows that the DW undercounted more than the NL (72.7% vs 91.6%, respectively) in the obese group ($P<0.001$). Additionally, the DW undercounted more in the obese group when compared to the normal weight group ($P<0.05$).

Pearson correlations (Table B-3, pg. 158) revealed that percentage of actual steps recorded by the DW was significantly correlated to BMI and weight ($P<0.05$). This finding should be interpreted with caution because we did not control for age or gender in the analysis. The percent actual steps for the DW showed a trend towards a significant correlation with maturity offset ($P=0.07$). Therefore, stepwise regression analysis was performed to determine which variable(s) significantly contribute to the percent of actual steps of the NL and DW (BMI percentile and maturity offset). BMI percentile was used (instead of BMI) to control for differences in the age and gender of the participants. The stepwise multiple regression analysis did not find any variable that significantly contributed to undercounting in the DW or NL.

Discussion

To our knowledge, this is the first study to use the SW as a criterion to evaluate the NL and DW in normal weight, overweight, and obese early adolescents 11-14 years of age under free-living conditions. The major findings of this study include: 1) The SW recorded significantly more steps than the DW and NL for each BMI category, 2) the percentages of actual steps recorded by the DW and NL were similar for normal weight and overweight groups, but the DW undercounted more than the NL in the obese group, 3) the DW undercounted more in the obese group when compared to the normal weight group, and 4) percentage of actual steps recorded by the NL was not affected by BMI and remained consistent regardless of BMI category.

Steps per day differences

Differences between the mechanisms may contribute to the differences seen among waist-mounted pedometers in the lab and free-living environment (6, 15, 27). For instance, piezoelectric accelerometers, such as the Actigraph 7164, commonly use a threshold of 0.30 G to count a step (25). The threshold to register a step for the DW, a spring-lever device, is 0.35 G (25) , while the threshold for the NL, a piezoelectric mechanism, is considered proprietary. Studies have also found that spring-levered devices, such as the DW, tend to undercount more as the tilt angle of the device increases; however, the NL is not as affected by the tilt angle (6, 7, 9). Studies using spring-levered devices have suggested that the walking volume of obese children is lower than that seen in normal weight children (8, 26). Part of the difference in walking volumes between BMI categories or with greater body fat percentage seen in previous studies my be due to the undercounting of spring-levered devices in obese subjects. This study reinforces the finding that BMI impacts pedometer accuracy among early adolescents within a free-living environment.

Digi-Walker

Our results confirm that the DW will undercount more in early adolescents with a high BMI, and they extend this observation to the free-living environment. This relationship is best described in Figure B-2 (pg. 162), which shows the relationship between the percent of actual steps for the DW and NL and BMI category. These findings are in agreement with previous research in adults and children (6, 17, 27). Melanson et al. (15) also found that the DW undercounted more with greater BMI during treadmill walking. Mitre et al. (17) found that spring-levered devices tended to undercount more in overweight/obese children compared to normal weight children during treadmill walking. Tyo et al. (27) also found that the DW undercounted more in adults with greater BMI when compared to the SW in a free-living environment. Also among adults, Crouter et al. (6) found that tilt angle, BMI, and waist circumference contributed to the DW undercounting actual steps. In this free-living study it was not feasible to measure the tilt angle because tilt angle is highly dependent upon how the pedometer is worn and can vary depending on the type of clothing to which the pedometer is attached.

The finding that the DW tends to undercount more in obese early adolescents has implications for the interpretation of studies that have used spring-lever devices to describe relationships between walking volume and adiposity, and for studies that have set steps per day goals based on BMI (4, 8, 26, 28). For example, Tudor-Locke et al. (26) established BMI referenced standards using secondary data analysis for steps per day including studies that utilized a spring-levered device in children 6-12 years of age.

Vincent et al. (28) examined the relationship of BMI and steps per day of children 6-12 years of age in the United States, Sweden, and Australia using a spring-levered pedometer. Belton et al. (4) used the DW to determine the relationship between step count and BMI of Irish children (6-9 y.o.). However, based on the current study, it is necessary to reexamine these research questions using a device that is not influenced by BMI, such as the SW or NL.

NL-2000

None of the variables included in the regression significantly contributed to the NL undercounting among early adolescents. The NL was very consistent regardless of BMI, counting 89.1%, 89.1%, and 91.6% of the steps for normal, overweight, and obese adolescent participants, respectively. This is consistent with previous research seen in adults and children (6, 18, 27). Crouter et al. (6) found that the accuracy of the NL was relatively unaffected by BMI while worn by adults walking on a treadmill. Nakae et al. (18) found that piezoelectric pedometers performed consistently regardless of weight in Japanese children during over-ground walking. The pedometers were within 4% of the actual steps. Tyo et al. (27) determined that the NL was not affected by BMI when compared to the SW worn by adults in a free-living environment and that the NL was relatively consistent across BMI categories.

Pedometer Accuracy

This study demonstrates that the DW undercounts more steps while being worn by obese adolescents in a free-living environment. The authors acknowledge there are many factors that could influence the position of waist-mounted devices, which could contribute to inaccuracies. Some examples include the position of clothing (i.e., on the hips or abdomen), style of clothing, and different body shapes. Data are currently unavailable regarding the effects of these variables and more studies are needed.

Strengths and Limitations

A major strength of the present study was the use of a criterion pedometer (SW), which allowed us to compare the accuracy of piezoelectric (NL) and spring-levered (DW) waist-mounted pedometers worn by adolescents in a free-living environment. However, there are limitations. This study included only 11-14 year old children. Therefore, the results may not be generalizable to other age groups. The SW is vulnerable to non-ambulatory movements such as leg swinging and heel tapping (11). However, studies have shown that these non-ambulatory movements would not make a meaningful contribution to the total number of steps over the course of a day (11) and that repeated shaking of the device will not cause additional counts due to a step-detection algorithm (19). Because this was a "free-living" study, the waist-mounted pedometers were attached to the waist-band of the child's clothing. Some researchers suggest placing waist-mounted pedometers on an elastic belt in order to minimize tilt angle (9). However, elastic belts can be rotated around the abdomen and moved superiorly and inferiorly, allowing the devices to migrate away from the optimal position. Therefore, we instructed each participant and parent/guardian on the proper placement and supplied a safety strap to attach the pedometer to their clothing.

Practical Applications

The DW has been used in numerous research studies in both adults and children and has a relatively low cost (<$25.00). Continued use of the DW allows for comparisons between studies and it allows for time trends to be described. However, researchers need to recognize the limitations of using a spring-levered device, such as the DW. The current study found that the DW undercounts more in obese adolescents. Therefore, use of the DW to examine relationships between step counts and adiposity in adolescents is not warranted. Using the DW in obese adolescents will result in low step counts, artificially strengthening the inverse relationship between walking volume and adiposity. The SW would be a preferred choice for researchers interested in counting all steps using a device unaffected by BMI or walking speed, but it is expensive (>$500 each). Use of a piezoelectric device, such as the NL, may be a more appropriate choice because of its consistency of measurement regardless of BMI category and lower cost (~$70.00 each). Researchers must be aware of these trade-offs and make informed decisions based on their population and research question.

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Part V

Conclusion

Waist-mounted pedometers can provide valuable information regarding walking volume in early adolescents and adults. These studies show that spring-levered devices, such as the Digi-Walker SW-200, undercount more in early adolescents and adults who are obese. Therefore, the Digi-Walker should not be used to determine relationships between walking volume and adiposity. The NL-2000, a piezoelectric pedometer, was not found to be significantly affected by adiposity. The NL-2000 is preferred for research and clinical applications. Studies that have used a spring-levered device to determine the relationship between walking volume and adiposity in these populations should be reevaluated. Additionally, future studies examining this relationship should consider using devices that are not affected by adiposity, such as the NL-2000.

Appendix A

Tables and Figures

Table A- 1: Descriptive characteristics of subjects by BMI category in adults (mean ± SD).

	Normal Weight (N=20)	Overweight (N=18)	Obese (N=18)
Age (y)	28.3 (± 12.2)	28.5 (± 8.9)	40.3 (±17.6)
Gender (% Female)	70.0%	55.6%	42.1%
Height (m)	1.69 (± 0.09)	1.73 (± 0.88)	1.71 (±0.1)
Weight (kg)	64.2 (± 9.4)	79.6 (± 7.6)*	98.0 (± 15.5)*†
BMI $(kg \cdot m^{-2})$	22.4 (± 1.5)	26.7 (± 1.2)*	33.2 (± 2.4)*†
Waist Circumference (cm)	71.9 (± 6.2)	84.1 (± 6.1)*	99.3 (± 10.2)*†
Hip Circumference (cm)	96.8 (± 5.2)	105.2 (± 3.9)*	112.3 (± 8.4)*†
WHR	0.74 (± 0.05)	0.80 (± 0.07)	0.88 (± 0.1)*†
SSRP	62.1 (± 11.0)	63.2 (± 14.0)	70.3 (± 15.2)

BMI, body mass index; WHR, waist-to-hip ratio; SSRP, slow step rate percent, * significantly different from normal weight, P<0.05, † significantly different from overweight, P<0.05.

Table A- 2: Mean pedometer error in adults.

			95% CI for Mean	
	Mean Pedometer Error (%)	SD (%)	Lower Bound (%)	Upper Bound (%)
Normal				
NL	-17.3	7	-20.5	-14.1
DW	-15.4	9.4	-19.7	-11.1
Overweight				
NL	-17.5	13.8	-24.6	-10.4
DW	-18.2	11.8	-24.3	-12.0
Obese				
NL	-23.9	14.4	-31.0	-16.7
DW	-32.8*#	17.3	-41.4	-24.2

NL, New Lifestyles NL-2000; DW, Digi-Walker SW-200; CI, confidence interval; SD, standard deviation; * DW significantly different from normal and overweight subjects (P<0.01); # DW obese significantly different from NL obese subjects (P<0.05).

Table A- 3: Pearson correlation coefficients (r) between the error of each hip-mounted pedometer and Slow Step Rate Percent, BMI, WC, HC, and WHR in adults.

Variable	NL error	P	DW error	P
SSRP	-0.658	<0.001	-0.589	<0.001
BMI	-0.230	0.088	-0.549	<0.001
WC	-0.193	0.155	-0.439	0.001
HC	-0.273	<0.05	-0.526	<0.001
WHR	-0.074	0.589	-0.226	0.095

SSRP, slow step rate percent; BMI, body mass index; WC, waist circumference; HC, hip circumference; WHR, waist-to-hip ratio.

.

Table B- 1: Descriptive characteristics of subjects by BMI category in early adolescents (mean ± SD).

	Normal Weight (N=33)	Overweight (N=21)	Obese (N=20)
Age (y)	13.1 (± 1.2)	12.8 (± 1.1)	13.2 (± 1.1)
Gender (% Female)	42.4	61.9	55.0
Height (m)	1.59 (± 0.10)	1.59 (± 0.07)	1.58 (± 0.05)
Weight (kg)	48.4 (± 9.3)	60.6 (± 6.6)*	86.9 (±17.4)*†
BMI ($kg \cdot m^{-2}$)	19.2 (± 1.8)	24.1 (± 2.5)*	33.6 (±6.6) *†
BMI percentile	58.2 (± 21.3)	89.3 (± 8.9)*	98.3 (± 1.4)*
Maturity offset (y)	-0.11 (± 1.40)	0.35 (± 1.14)	-0.83 (± 1.37) *

BMI, body mass index, * significantly different from normal weight, P<0.01, † significantly different from overweight, P<0.01.

Table B- 2: Comparison of NL-2000 and Digi-Walker to the StepWatch in early adolescents.

			95% CI for Mean	
	Actual Steps (%) †	SD (%)	Lower Bound (%)	Upper Bound (%)
Normal				
NL	89.1	13.1	84.5	93.8
DW	86.7	16.7	80.8	92.6
Overweight				
NL	89.1	9.9	84.6	93.6
DW	84.6	13.8	78.3	90.9
Obese				
NL	91.6	11.1	86.4	96.8
DW	72.7*#	19.8	63.4	82.0

NL, New Lifestyles NL-2000; DW, Digi-Walker SW-200; CI, confidence interval; SD, standard deviation; † StepWatch used a criterion number of steps; * DW Normal significantly different from DW obese subjects (P<0.05); # DW obese significantly different from NL obese subjects (P<0.001).

Table B- 3: Pearson correlation coefficients (r) between the error of each hip-mounted pedometer and BMI, Slow Step Rate Percent, maturity status, and weight in early adolescents.

Variable	NL Percent Actual Steps	P	DW Percent Actual Steps	P
BMI	0.031	0.796	-0.318	0.006
BMI percentile	0.103	0.383	-0.169	0.151
Maturity offset	0.030	0.798	0.215	0.066
Weight (kg)	0.021	0.860	-0.311	0.007

BMI, body mass index.

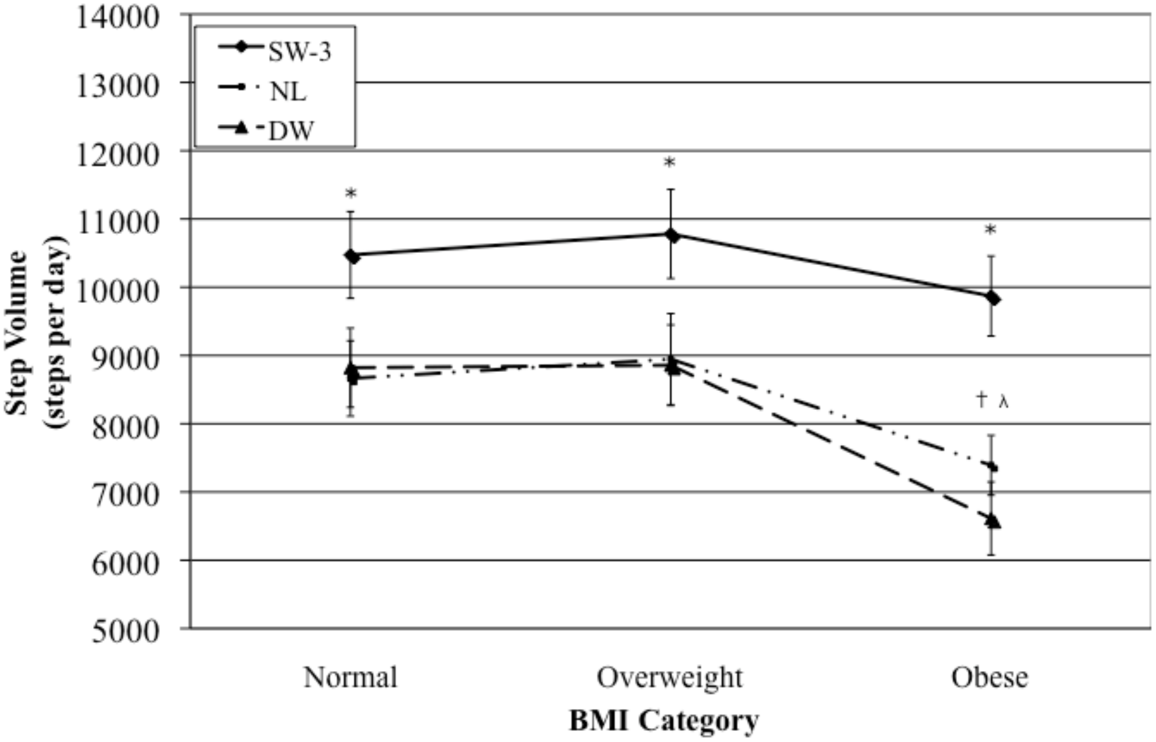

Figure A- 1: Step volume (mean ± SE) for each device by BMI category in adults. * SW-3 significantly different from NL and DW ($P \leq 0.001$), † NL obese is significantly different from DW obese ($P<0.05$), λ DW obese is significantly different from DW normal weight and overweight ($P=0.01$).

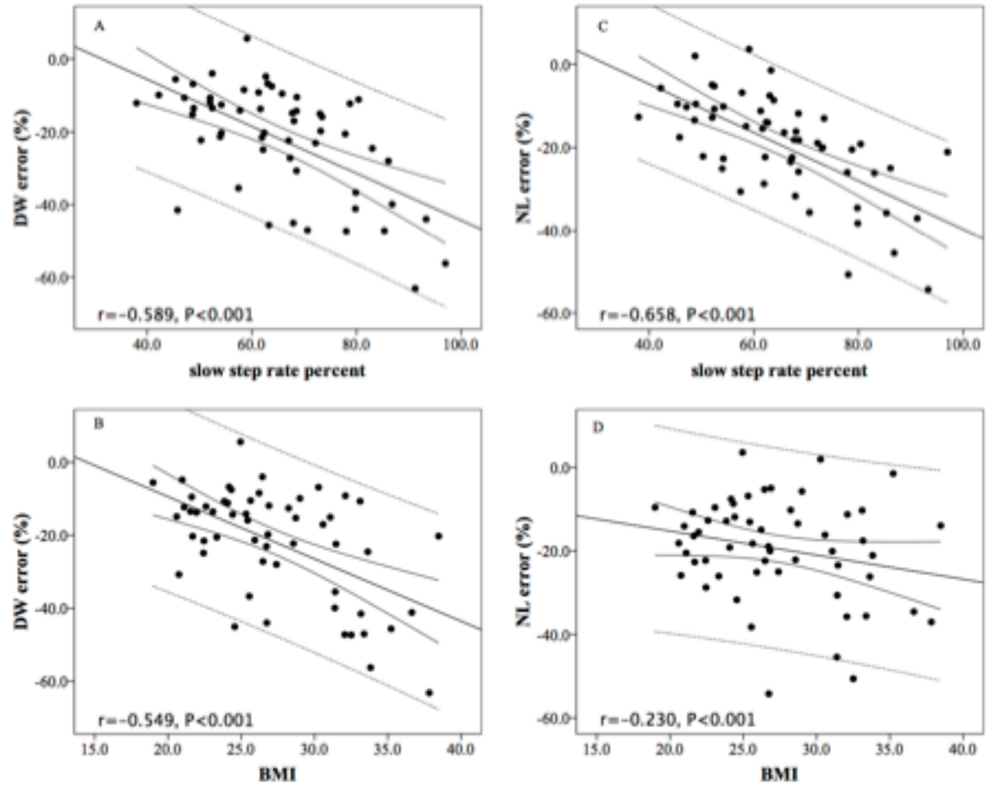

Figure A- 2: Correlation of pedometer error with increasing slow step rate percent and BMI with 95% confidence and prediction intervals in adults.

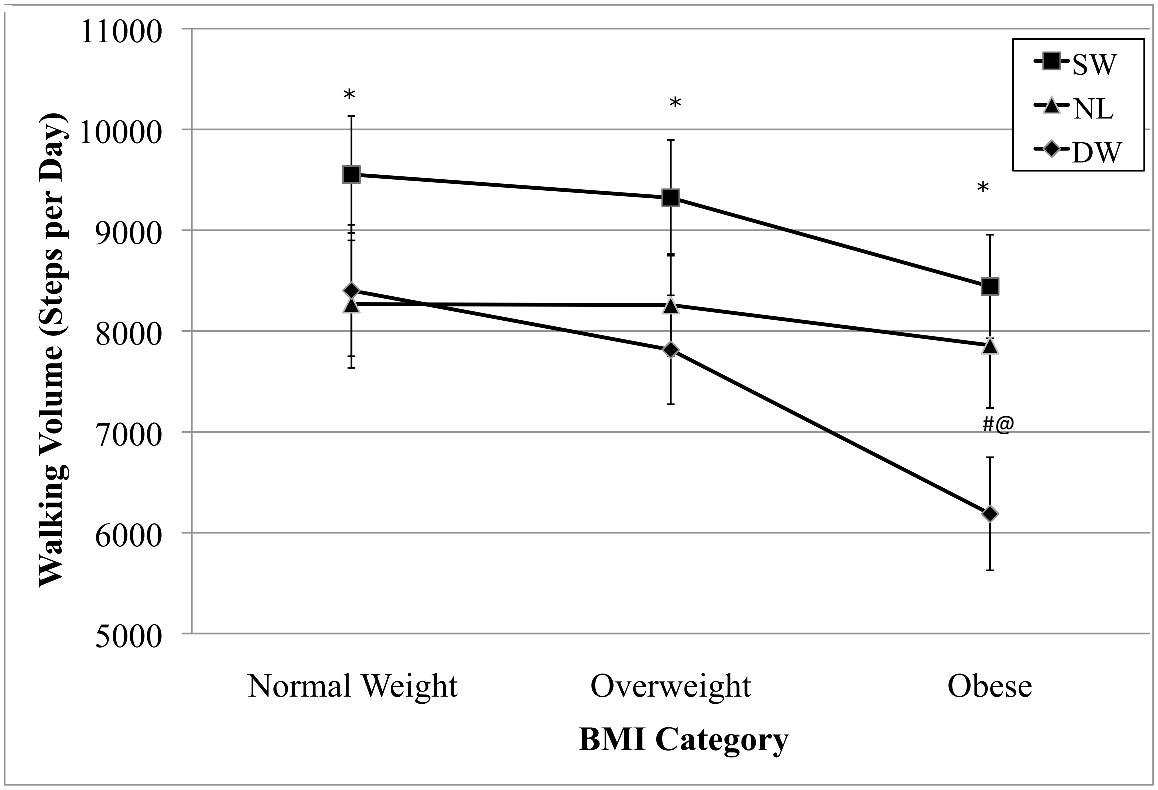

Figure B- 1: Step volume (± SE) for each device by BMI category in early adolescents. * SW-3 significantly different from NL and DW ($P \leq 0.05$), # DW obese is significantly different from NL obese ($P < 0.001$), @ DW obese significantly different from DW normal weight ($P < 0.05$). BMI, body mass index.

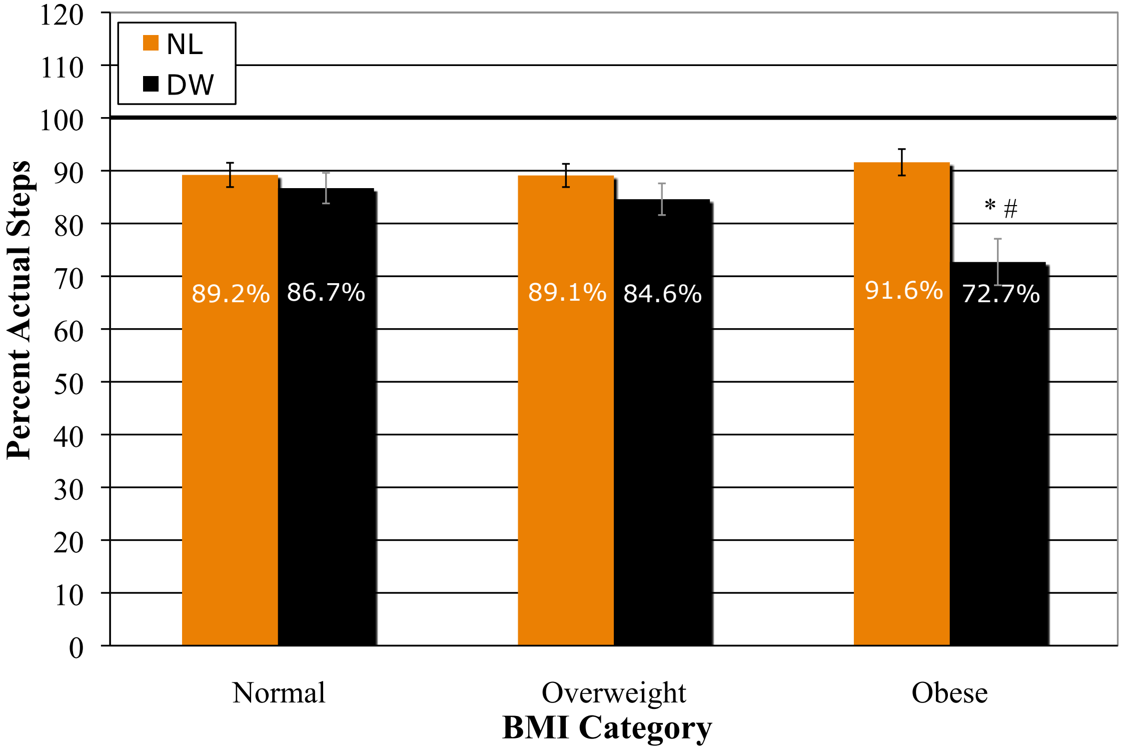

Figure B- 2: Percent of actual steps by BMI category in early adolescents. * DW obese significantly different from NL obese, # DW obese significantly different from DW normal. NL, NL-2000; DW, Digi-Walker SW-200; BMI, body mass index. * DW Normal significantly different from DW obese subjects ($P<0.05$); # DW obese significantly different from NL obese subjects ($P<0.001$).

Appendix B

Part III
Informed Consent Form and Flyer

Informed Consent Form

The Accuracy of Pedometers in the Free Living Environment

Investigators: Brian Tyo, M.A.
Dr. Dixie Lee Thompson
Address: The University of Tennessee
Department of Exercise, Sport and Leisure Studies
1914 Andy Holt Ave.
Knoxville, TN- 37996
Telephone: 865-974-6040

Purpose

You are invited to participate in a research study that examines **the accuracy of pedometers.**

Exclusion Criteria

If you have an internal defibrillator, pacemaker, or joint replacement you will not be allowed to participate in the study. Your should not volunteer for this study if you are pregnant, have difficulty walking, and/or use a cane or other device when you walk.

Procedures

You will be asked to come to the Applied Physiology Lab on 2 separate occasions. The first appointment will last approximately 30-45 minutes. You will be asked not to eat or exercise for 4 hours prior. You will need to wear or bring light weight clothing such as shorts and a t-shirt. Your height will be measured. Body fat will be estimated using a machine that looks much like a typical bathroom scale with the addition of handles. While standing on the scale with your bare feet and holding the handles, electrical currents will be used to estimate your body composition. This process takes less than 1 minute and you will not be able to feel the currents used to estimate body fat. Before you leave, you will be instructed how to properly wear the pedometers that are assigned to you. One pedometer will be attached to each hip in line with the leg. The third pedometer will be attached to your ankle. The pedometers are to be worn during all waking hours except while sleeping, swimming, or bathing.

Understand that you will be responsible for the pedometers in your possession and it is expected that you return the pedometers at the end of the study. If you have any problems with the pedometers, please call Brian Tyo at 865-974-6040.

Your second appointment will last approximately 45-60 minutes and will be made for eight days after the first appointment. This appointment is to turn in your pedometers, log sheet, and answer 2 brief surveys that ask about your daily physical activity and exercise.

Risks and Benefits

The study asks that you do not change anything with your physical activity levels. Therefore, there are few risks associated with this study. Slight rubbing could occur at the attachment of the ankle pedometer. Following the instructions carefully will minimize this risk. There is the possibility that unauthorized individuals could access your test results. This risk will be minimized by storing all data using subject identification numbers rather than by name.

Confidentiality

The information obtained from these tests will be treated as privileged and confidential and will not be released to any person without your consent. The information may be used in research reports or presentations, but your name and other identifying information will not be disclosed.

Contact Information

If you have any questions at any time about the study or the procedures, (or you experience adverse effects as a result of participating in this study), contact the investigator Brian Tyo, btyo@utk.edu or (865) 974-6040. If you have questions about your rights as a participant, contact Research Compliance Services of the Office of Research at 865-974-3466.

Right to Ask Questions and to Withdraw

You are free to decide if you want to participate in this study or withdraw from it at any time.

Before you sign this form, please ask questions about any aspects of the study that are unclear to you.

- -

Consent

By signing this form, I am indicating that I understand what I will be asked to do in this study and agree to participate.

Your signature ____________________ Date ____________

Researcher’s signature ____________________ Date ____________

The University of Tennessee

The Center for Physical Activity and Health

The University of Tennessee's Center for Physical Activity and Health is currently seeking volunteers to participate in a research study to examine the accuracy of pedometers. No change in activity or exercise will be required. A FREE body composition test using the Tanita Body Composition Analyzer will be provided.

Subject Requirements:

*18-60 years of age
*Willing to wear activity monitors for eight days
*No internal defibrillator, pacemaker, or joint replacement
*Must be able to walk without difficulty and without the use of a cane or other device
*Must not be pregnant

If you would like to participate in this research study please contact Brian Tyo at 865-974-6040 or email at btyo@utk.edu.

NL-2000

StepWatch

Digi-Walker

Appendix C

Part IV

Informed Consent, Assent, and Flyer

INFORMED CONSENT FORM

TITLE OF THE STUDY: The Accuracy of Pedometers in Children

PURPOSE OF THE STUDY

Your child is invited to take part in a research study. The purpose is to compare commonly used step counters (pedometers) in children while they wear them during a typical day.

EXCLUSION CRITERIA

Your child should not volunteer for this study if he/she has difficulty walking and/or needs a cane or other assistive device when walking.

PROCEDURES TO BE FOLLOWED

Your child will meet with the researcher for approximately 20 minutes. Your child should wear light-weight clothing, similar to a physical education class. During this time, your child's standing height, seated height, and weight will be measured. Shoes must be removed for these measurements. You and your child will then be instructed how to properly wear three step counters. One step counter will be attached to the pants on each hip in line with the thigh. The third step counter will be attached to the ankle. Your child will be asked to wear all step counters simultaneously over a 24-hour period. The step counters are to be removed while bathing, sleeping, or playing in sports that could damage the step counters (e.g., football). An instruction sheet will be provided detailing the position of the step counters. If you have any problems or questions please call the phone number listed below. I will call you at the end of the testing day.

You will send the step counters and instruction paper back to me using the box that I give you. After I receive the step counters and the instruction paper in the mail, I will send 2 movie passes in the mail.

POTENTIAL RISKS OF PARTICIPATION

This research study involves minimal risk to the children since we are simply monitoring physical activity. Height and weight will be measured which could be embarrassing for some participants. This will be minimized by providing privacy for these measurements. There is the possibility that unauthorized individuals could access the test results. This risk will be minimized by storing data using subject identification numbers rather than by name, all electronic data will be stored on a password protected computer, and all forms will be stored in a locked cabinet.

POTENTIAL BENEFITS OF PARTICIPATION

As an incentive to participate, your child will receive 2 free movie passes upon return of the step counters and instruction sheet. Otherwise, there is no direct benefit for participating. However, this study will provide researchers and the general public with information on the accuracy of these step counters in children.

CONFIDENTIALITY

Only Brian Tyo and Dixie Thompson, Ph.D., and you will have access to any of your child's information during this research project. The original, signed consent and assent forms will be kept in a locked cabinet at the University of Tennessee. The results of the study will be published, but your child's name will not be used in any of the material published.

LIABILITY

There will be no payment for treatments or injury resulting from participation in this study.

RESEARCH RELATED INQUIRIES

Any questions concerning this study may be addressed to the following:
Investigator: Brian Tyo, M.A.
Faculty Advisor: Dixie Thompson, Ph.D
Address: The University of Tennessee
Department of Exercise, Sport, and Leisure Studies
1914 Andy Holt Ave.
Knoxville, TN- 37996
Telephone**:** 865-974-5910

PARTICIPANT RIGHTS INFORMATION

General questions concerning your rights as a participant in research protocols or questions about research related issues may be addressed to the Institutional Review Board Chairman, East Tennessee Children's Hospital through his secretary at (865) 541-8477 or Brenda Lawson of the Research Compliance Services of the Office of Research at University of Tennessee at (865) 974-3466.

VOLUNTARY PARTICIPATION STATEMENT

Participation in this study is voluntary. There will be no penalty for refusal to participate, and your child may withdraw from the study at any time.

PARENT PERMISSION

I have received a copy of this consent form. By signing this informed consent form, I am indicating that I have read and understood this document. I have been given the opportunity to ask questions. By signing this form I indicate that I agree to allow my child to serve as a participant in this research study.

___________________________ __________________
Parent's Signature Date

____
Parent's Printed Name

___________________________ __________________
Investigator's Signature Date

INFORMED ASSENT FORM

TITLE OF THE STUDY: The Accuracy of Pedometers in Children

Brian Tyo is a student at the University of Tennessee and will be doing this study. You can call Brian at (865) 974-5910 or email him at btyo@utk.edu if you have any questions.

PURPOSE

You are invited to be in a study. The study will compare different step counters worn by kids, in sixth through eighth grade.

PROCEDURES

You will meet with me for about 20 minutes. You should wear clothes that you would normally wear to your physical education class. Your height will be measured without your shoes while you are standing and while you are sitting in a chair. Your weight will also be measured without your shoes. You will be shown how to wear three step counters. One step counter will attach to your pants on your right hip, one will attach to your pants on your left hip, and the third will be on your ankle. You are to wear all of the step counters at the same time for one day. Your should remove the step counters when you take a bath, while you sleep, and when you are playing in sports that could break the step counters (e.g., football). An instruction paper will be provided showing where the step counters should go.

You will send the step counters and instruction paper back to me using the box that I give you. After I receive the step counters and the instruction paper in the mail, I will send you 2 movie passes in the mail.

BENEFITS

There are no direct benefits to you. But, you will get 2 free movie passes when you return the step counters and instruction paper.

RIGHT TO WITHDRAW

It is ok if you decide not to be in the study. Even if you start the study, you can stop at any time.

______________________________ Your Name (Optional)	____________________ Date
______________________________ Investigator's Signature	____________________ Date

The University of Tennessee

Attention: Kids 11-14 years of age

Pedometer Study

Participants Must:

- Be 11-14 years old
- Wear Pedometers for 1 day
- Attend a session to measure your height & weight

After completing the study, each participant will receive 2 complimentary *Movie Passes!!*

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Vita

Brian Matthew Tyo was born in Marion, Indiana on November 22, 1975. He was raised in Wabash, Indiana where he attended school and graduated from Northfield High school in June of 1994. He completed his Masters of Arts degree from Central Michigan University in Exercise Science in May of 2001. He then went to work for Biomet, Inc. selling orthopaedic implants and medical supplies. After working with Biomet for six years, he accepted a position at the University of Tennessee-Knoxville in the Department of Exercise, Sport, and Leisure Studies. He graduated with a Doctor of Philosophy degree in August 2010. He then accepted a faculty position at Columbus State University in Columbus, Georgia.