

INFLUENCE OF PEDOMETER TILT ANGLE ON STEP COUNTING VALIDITY
DURING CONTROLLED TREADMILL WALKING TRIALS

by

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ABSTRACT

Pedometers are tools frequently used to monitor walking-related physical activity patterns of overweight and obese populations. However, there is a known association between increasing body mass index (BMI) and decreasing pedometer accuracy. The decrease in pedometer accuracy has been attributed to tilt angle, but the specific tilt angle where pedometers fail to maintain accuracy is unclear. **PURPOSE:** The purpose of this study was to test two popular pedometer mechanisms, accelerometry- and pendulum-based, to determine the specific tilt angle where the pedometers fail to maintain step counts accurately. **METHODS:** Twenty subjects (10 men, Mean±SD: 25.4±4.2 yrs, 184.4±5.3 cm, 76.7±6.3 kg; 10 women: 21.6±3 yrs, 166.1±6.3 cm, 56.7±6.7 kg) walked two sets of 21 trials at a combination of treadmill speed (67.0, 80.4, 93.8 m/min) and tilt angle (-30,-20,-10, 0,+10,+20,+30°) while wearing two pedometers; the experimental pedometer attached to a custom-built pedometer gimbal for altering tilt angle, and the control pedometer in a neutral position ($\pm 2^\circ$ of 0°). The pedometers were worn on each hip just anterior to the iliac crest in line with the mid-axillary line of the thigh. The first set of trials tested one pedometer mechanism, while the second set of trials tested the second pedometer mechanism in a counterbalanced order. Mean steps from the experimental pedometer were compared to the control pedometer for each trial ($\Delta\text{Step}=\text{Experimental}-\text{Control}$) using a 3-factor RMANOVA at an alpha level of 0.05. **RESULTS:** Mean Δsteps for the accelerometry-based pedometer and the pendulum-based pedometer differed significantly ($P<0.05$) at tilt angles $>\pm 10^\circ$ for treadmill speeds ≤ 67.0 and 80.4 m/min, respectively. However, mean Δsteps across treadmill speeds was much lower for the accelerometry-based pedometer (Mean±SE: 4.9±1.9, 2±1.9, 4±1.9, 5±1.9, 4±1.9, 9±1.9 steps) than the pendulum-based pedometer (14.1±1.9, 4.2±1.9, 8.9±1.9, 6.8±1.9, 6±1.9, 38.1±1.9 steps) across conditions $> 0^\circ$ (-30,-20,-10, +10, +20, +30°, respectively). **CONCLUSIONS:** Increasing tilt angle caused a decrease in pedometer accuracy for both pedometer mechanisms, although the accelerometry-based pedometers were less affected. Negative tilt angles had less effect on pedometer accuracy than positive tilt angles, and the combination of increasing positive tilt angle and slower speeds had the greatest impact on step count accuracy.

CHAPTER 1

INTRODUCTION

Physical activity can mitigate the adverse health effects associated with obesity, which the American College of Sports Medicine (ACSM) defines as a body mass index (BMI) of $\geq 30.0 \text{ kg/m}^2$ (American College of Sports Medicine [ACSM], 2005). Obesity is a risk factor for coronary artery disease, the number one cause of death in the United States. A related concern is the age at which individuals are becoming obese. For example, co-morbidities, the simultaneous appearance of two or more physical illnesses, have been seen in children as young as six years old (Torgan, 2002). According to the 1992-2002 National Health and Nutrition Examination Survey, 30% of adults over the age of 20 are obese, and the percentage of overweight children has tripled to 16% since 1980 (National Center for Health Statistics [NCHS], 2004). The recent rise in obese children and adults is reflective of changes in society such as increased consumption of saturated fats, more passive leisure time pursuits, and automated transport (World Health Organization [WHO], 2003). However, obesity and the associated health consequences are preventable with increases in physical activity.

There is a strong association between moderate increases in physical activity and improved health. For instance, minimal amounts of physical activity can reduce the likelihood of developing obesity, diabetes, and cardiovascular disease (CVD) (US Department of Health and Human Services [USDHHS], 1996). Physical activity is also important for maintenance of independence and improved quality of life in older adults.

As a result, minimum physical activity standards have been established by the Surgeon General as 30 minutes of moderate intensity physical activity on most if not all days of the week (USDHHS, 1996). However, many individuals have trouble meeting the standards due to difficulties in translating the guidelines into specific activities. It is easy to identify frequency, duration, and type of activity, but often difficult for individuals to gauge intensity. Therefore, researchers must have an accurate assessment tool for evaluating physical activity habits in order to determine if individuals are meeting the guidelines.

Pedometers are popular physical activity assessment tools because they are objective, simple to use, and relatively inexpensive. Pedometers utilize a step counting function to objectively quantify walking-related physical activity. There are two common step-counting mechanisms utilized by pedometers; pendulum and accelerometer. The pendulum-based pedometers use a spring lever which swings in an arc in response to walking impact forces, causing the instrument to count a step. The accelerometry-based pedometer contains a piezo-electric element which deflects in response to movement in one or more planes, measuring displacement and counting a step.

The accuracy of both pedometer mechanisms have been well documented and acceptable accuracy has been established for controlled treadmill walking trials and free-living studies as 3% and 10%, respectively (Crouter, Schneider, Karabulut & Bassett, 2003). Le Masurier and Tudor-Locke (2003) compared a pendulum-based pedometer to an accelerometry-based pedometer and found the step counts for both pedometers were equivalent at speeds ≥ 67 m/min for normal weight individuals in controlled treadmill

trials. In a comparison study, pendulum-based pedometers were found to be 95% accurate in 400 m outdoor walking trials when compared to a hand tally (Schneider, Crouter, Lukajic & Bassett, 2003).

A potential threat to the accuracy of pedometers is the tilt angle due to incorrect wearing position or excess abdominal adiposity. Tilt angle refers to the degree that the pedometer deviates from zero on either a medial-lateral or anterior-posterior axis. The extent to which tilt angle affects accuracy is a concern because pedometers are routinely used to monitor the activity patterns of overweight and obese individuals. Crouter, Schneider and Bassett (2005) compared the accuracy of accelerometry- and pendulum-based pedometers in overweight and obese individuals (Mean BMI \pm SD; 32.6 \pm 4.6 kg/m²). They found that the pedometer tilt angle significantly influenced the accuracy of the pendulum-based pedometers but not for the accelerometry-based pedometers. The accuracy of the pendulum-based pedometers decreased further with increasing BMI and waist circumference. However, the tilt angle was not systematically altered in this study. Instead, subjects were all overweight or obese and the angle was measured with a protractor as it naturally attached on each subject. Therefore, the extent to which tilt angle affects pedometer accuracy remains unclear. Information regarding tilt angle will aid the researcher in choosing the appropriate assessment tool in order to garner accurate information about at risk populations.

Statement of Purpose

The purpose of this study was to determine the relationship between pedometer tilt angle and step counting accuracy. This was accomplished by comparing the total steps accumulated between an experimental pedometer at an altered tilt angle and a neutral positioned pedometer (i.e., the control) at different treadmill walking speeds. The secondary purpose of this study was to compare the step counting accuracy between pendulum- and accelerometry-based pedometers for the same walking speeds and tilt angles.

Hypotheses

The null hypothesis was mean steps for the experimental pedometer at any combination of tilt angle and treadmill speed would equal the mean steps for the control pedometer. The alternative hypothesis was that mean steps for the experimental pedometer at any combination of tilt angle and treadmill speed would be less than the mean steps for the control pedometer. Steps for the experimental pedometer were expected to be less than steps for the control based on previous research. Crouter et al. (2005) found that the pendulum-based pedometer failed to maintain step counts accurately at $> 10^\circ$, while the accelerometry-based pedometer failed to maintain accurate step counts at $> 15^\circ$.

$$H_0: M_{E(A,S)} = M_{C(A,S)}$$

$$H_a: M_{E(A,S)} < M_{C(A,S)}$$

Where $M_{E(A,S)}$ is the mean steps for an experimental pedometer (M_E) at any combination of tilt angle (A) and treadmill speed (S) and $M_{C(A,S)}$ corresponds to the mean steps for the control pedometer (M_C) at the same tilt angle and treadmill speed.

The secondary null hypothesis was mean steps for a pendulum-based pedometer at any combination of tilt angle and treadmill speed would equal the steps for an accelerometry-based pedometer. The alternative hypothesis was that mean steps for a pendulum-based pedometer at any combination of tilt angle and treadmill speed would not equal the steps for an accelerometry-based pedometer for at least one combination of tilt angle and treadmill speed.

$$H_0: M_{P(A,S)} = M_{AC(A,S)}$$

$$H_a: M_{P(A,S)} \neq M_{AC(A,S)}$$

Where $M_{P(A,S)}$ corresponds to the mean steps for the pendulum-based pedometer (M_P) at any combination of tilt angle (A) and treadmill speed (S) and $M_{AC(A,S)}$ corresponds to the mean steps for the accelerometry-based pedometer (M_A) at any combination of tilt angle (A) and treadmill speed (S).

Limitations

1. Only one model of pendulum- and accelerometry-based pedometers were used in this study. Therefore, results are only applicable to these specific models and pedometer mechanisms. Pedometers that utilize other mechanisms will need to be tested as they become available.
2. Testing was performed only during controlled treadmill walking trials. Results may vary with different walking surfaces or walking-based activities.
3. Pedometers were only worn on the hip. Alternative placement such as the ankle may have different results.

Assumptions

1. It was assumed that treadmill walking accurately reflects free-living walking.
2. It was also assumed that artificial tilting mimics the deviations from neutral that occur with overweight and obese individuals.

Operational Definitions

1. Tilt Angle – the positive or negative degree to which the pedometer deviates from zero degrees (parallel with gravity) on a medial-lateral axis.

2. Positive Tilt Angle – an anterior rotation of the pedometer about a medial-lateral axis in the sagittal plane.

3. Negative Tilt Angle – a posterior rotation of the pedometer about a medial-lateral axis in the sagittal plane.

4. Pedometer Gimbal – an instrument to systematically alter the pedometer tilt angle on a medial-lateral and/or an anterior-posterior axis.

CHAPTER 2

REVIEW OF LITERATURE

Introduction

Pedometers are objective assessment tools that are utilized in many physical activity interventions. There are many obstacles that must be overcome with any physical activity intervention that include the ability to implement on a large scale, cost effectiveness, and the ability to accurately measure free-living physical activity habits of the individuals. The objective quantification of activity becomes increasingly difficult when working with special populations such as those with physical handicaps, an aging population, children, or the obese.

Alternative Measures of Physical Activity

There are several known procedures for gathering physical activity information, many focusing on free-living energy expenditure (EE) data. Free living refers to the subject's normal activities throughout the course of the day. However, many methodologies are not feasible for a large group of individuals over an extended period of time. Direct and indirect calorimetry are expensive lab-based tests that are limited by an inability to gather data over extended periods of time (e.g. two weeks). A portable metabolic system might be utilized, but it is unreasonable to assume individuals would want to wear a face mask for an extended period of time. Therefore, an estimation of the caloric cost of free-living activities cannot be gathered in this manner.

Survey procedures, while requiring minimal time and expense, are based on perceived activity. Previously, very little was known about the reliability and validity of such measures (Laporte, Montoye & Caspersen, 1985). However, in recent years several large scale physical activity surveys have been completed such as the National Health and Nutrition Examination Survey (NHANES) and the Behavioral Risk Factor Surveillance System (BRFSS). While these studies have provided invaluable information about health risks in the United States, they give little to no information about an individual.

The doubly labeled water technique is another technique for collecting EE data. This method requires the ingestion of a known concentration of oxygen and hydrogen isotopes that naturally occur in the body. The rate that it is excreted is used to estimate energy expenditure (McArdle, Katch & Katch, 1991). Although this methodology has proven accurate and allows for data collection outside the laboratory setting, it is expensive and can cost as much as \$1200 per subject. The subject would be required to collect every urine specimen throughout the day, which has the potential for compliance issues and attrition.

Accelerometers are objective assessment tools that have been utilized to assess free-living physical activity. An accelerometer, also referred to as an activity monitor, uses a piezo-electric element that bends with movement, measuring both the speed and duration of activity. Meijer, Westerterp, Koper & Ten Hoor (1989) assessed the ability of accelerometers to accurately measure EE against a heart rate monitor in a laboratory setting and in activities of daily living in a normal population. The standard error for both

free living and laboratory settings was much lower in this experiment than previously reported (5.5 J/kg versus 9.1 J/kg). However, the true impact of this study is difficult to interpret due to the small sample size during free living conditions. Only four subjects participated in the free living portion of the study making the results hard to generalize to a larger population or to find statistical significance.

In another study, Davis and Fox (2006) assessed the ability of the Actigraph activity monitor to measure free living EE in older adults. Data on 170 individuals aged at least 70 years were analyzed. Participants wore an activity monitor during waking hours for a period of seven days and kept a detailed journal. Epochs were set to one minute and the data were analyzed against a control group of 45 young adults. The researchers found that there was a significant difference between the amount of time spent being active between the control and experimental groups, and the number of minutes spent at moderate intensity activity was much lower for the older adults. It was concluded that the number of older adults meeting the minimum activity standard was significantly lower than the young adults.

While accelerometers are light, waterproof and unobtrusive, they are relatively expensive and not as simple to use as pedometers. Accelerometers can cost as much as \$500 per unit and an additional \$500 for the computer software. Therefore, pedometers have emerged as the focal point of many physical activity studies due to their low cost, unobtrusiveness, and objectivity. Many researchers have tested the validity and reliability of these instrumentations in laboratory and free-living settings.

Pedometer Validity and Reliability

Pedometer validity refers to the ability of the instrument to measure the number of steps taken accurately. Reliability is the degree to which a measurement instrument is free from random error and systematic bias. Test- retest reliability refers to the ability of a pedometer to yield the same result under the same experimental conditions. Acceptable accuracy for pedometers has been established for controlled treadmill walking trials and free-living studies as 3% and 10%, respectively (Crouter et al., 2003).

Pedometer validity and reliability have been tested often, as new products have become available on the market. The researcher must be aware of pedometer mechanisms and models that may be less reliable than a counterpart. In an early comparison study of five different brands of accelerometry-based pedometers, Bassett et al. (1996) found the brands tested all produced steps within 11% of the actual number and the step variability was not statistically significant. However, the test distance was 3 miles, and statistical significance may have emerged if the distance was longer or individuals were monitored over several days.

Schneider, Crouter & Bassett (2004) compared 13 commonly used pedometers in a free living scenario. Twenty subjects donned a control pedometer and an experimental pedometer for a period of 13 days. Subjects recorded daily steps and kept a daily journal. This process was repeated until each subject had worn all 13 brands of pedometers. Researchers found that some pedometers underestimated steps by up to 25%, while others overestimated by up to 45%. In another study, researchers tested the validity of ten different brands of electronic pedometers on step counting, distance, and EE in controlled

treadmill tests (Crouter et al., 2003). Ten volunteers walked on a treadmill for a period of five minutes at each experimental speed and grade. Steps were compared to a hand tally, indirect calorimetry for EE, and distance was calculated based on treadmill speed and time. Investigators found that six of the pedometers gave step counts within $\pm 1\%$ of the actual values at speeds 80 m/min and above. Only four pedometers gave acceptable readings at speeds of 54 m/min, where the step count was within 10% of actual steps taken. Therefore, pedometer accuracy tends to be lower for slower speeds of locomotion.

Pedometer reliability was assessed as part of a larger health behaviors study (Felton, Tudor-Locke & Burkett, 2006). Subjects were college-aged women recruited from an introductory health class and were considered moderately active and active. Participants were asked to wear a pedometer at the waist during waking hours for two seven-day periods twelve weeks apart, and data were collected each day during the class period. The EE for each individual was estimated based on steps taken. The intraclass correlation coefficient (ICC) between weeks for the group means was 0.72, while the individual variance was much higher. The researchers concluded that pedometers are more reliable for estimating EE from step counts of a group than for an individual. The ICC in this study was much lower in comparison to other studies on sedentary populations. Therefore, researchers also concluded that variation in moderately active and active populations may be greater because these groups are less consistent in their behavior patterns.

Step counting algorithms have recently been added to accelerometers and, with the addition of this feature, accelerometers can function as pedometers. The validity of

the algorithm was tested with eight Actical accelerometers at six different speeds on a shaker table (Esliger et al., 2007). In the secondary part of the study, 38 volunteers wore the accelerometers at six different treadmill speeds which corresponded to the shaker table speeds. The accelerometry-based pedometers underestimated steps at the slowest walking speed of 50 m/min ($r = 0.52$), but correlated highly ($r = 0.99$) at speeds > 50 m/min. It was concluded that for healthy individuals walking at normal speeds, the step counting function of the Actical accelerometer was a valid assessment tool.

Comparisons of Pendulum- and Accelerometry-based Pedometers

There has been a trade-off between sensitivity and specificity when using pedometers. A more sensitive pedometer may collect data more accurately at slower walking speeds. However, the pedometer may also over count steps when walking at faster speeds or during non-ambulatory activity, decreasing the specificity. Specificity refers to the pedometers ability to distinguish between actual steps taken and non-ambulatory activity. Therefore, the pendulum-based pedometers have been compared to accelerometry-based pedometers to determine if one type has better matched the demands of sensitivity and specificity.

Le Masurier and Tudor-Locke (2003) tested the sensitivity and specificity of the CSA accelerometer and the Yamax pedometer. Testing consisted of walking trials on a treadmill and a non-ambulatory activity; riding in a motorized vehicle on paved roads. Forty volunteers either walked on the treadmill or road in the vehicle. Body mass index (BMI), a height to weight ratio, was an exclusion criterion. Researchers found no

significant differences between the pendulum- and the accelerometry-based pedometers at the 4 fastest walking speeds. However, the pendulum-based pedometer detected significantly fewer steps at the slowest walking speed (54 m/min). In the secondary portion of this study, both pedometers detected erroneous steps. However, the accelerometry-based pedometer detected seventeen times the number of erroneous steps as the pendulum-based pedometer. Thus, the accelerometry-based pedometer may be more sensitive while the pendulum-based pedometer may be a more specific tool.

The CSA accelerometers and Yamax pedometers were also compared during free-living conditions to determine concurrent validity (Tudor-Locke, Ainsworth, Thompson & Matthews, 2002). Volunteers wore both types of pedometers over a two week interval and steps were analyzed using dependent samples t-tests. While the step counts were not significantly different, there was still a 2000 step/day practical difference between the pedometers, with the accelerometry-based pedometer averaging higher step counts.

There are unique considerations for the researcher when collecting data on special populations. For instance, Trost, McIver and Pate (2005) highlighted several issues that need to be considered when collecting accelerometry-based pedometer data. However, these issues are applicable to data collections with a pendulum-based pedometer as well. These considerations were product selection, number of monitors to be worn, placement, epoch length, and number of days necessary to estimate habitual activity. The authors found no definitive evidence that a particular make and model of pedometer were superior. Pedometer placement on the hip or lower back had the most accurate results. Optimal epoch lengths remain undetermined due to the limitation of most brands to one

minute intervals for extended periods of wearing time. Extended periods of wearing time are necessary due to the high number of monitoring days before behavior patterns are known to the researcher. In subsequent studies, it was determined that behavior patterns of adults can be determined with accuracy after 3 to 5 days of monitoring while children require 4 to 9 days (Matthew, 2005; Freedson, Pober & Janz, 2005).

One group that is frequently monitored with pedometers is overweight and obese adults. However, it has been determined that pedometer validity decreases as BMI increases (Sheperd, Toloza, McClung & Schmalzried, 1999; Crouter et al., 2005). Very few studies have examined the mechanism behind the decreased validity. Sheperd et al. (1999) identified decreasing accuracy in both pendulum- and accelerometry-based pedometers with increasing BMI during controlled outdoor walking tests. The pendulum-based pedometer had much higher error than the accelerometry-based pedometer when BMI was ≥ 30 kg/m². The pendulum-based pedometer only recorded a portion of the steps actually taken (21% discrepancy). However, BMI was not the primary experimental condition being tested in this study; steps and BMI were analyzed retrospectively. Therefore, the researchers were unable to clarify the relationship beyond a negative correlation between increasing BMI and pedometer accuracy.

Crouter et al. (2005) also evaluated the effect of BMI on accelerometry- and pendulum-based pedometer accuracy. Participants were 40 adults with a BMI > 25 kg/m² (32.6 ± 4.6 kg/m²). In the first part of the study, subjects wore both types of pedometers while walking on a treadmill at five different speeds (54.0, 67.0, 80.0, 94.0, and 107.0 m/min). Tilt angle was measured with a protractor as the pedometer naturally attached on

each individual's clothing. During the free-living portion of the study, subjects wore an accelerometry- and pendulum-based pedometer for a 24 hour period. For both the controlled and free-living tests, the accuracy for both pedometer mechanisms decreased with increasing tilt angle due to excess abdominal adiposity. However, tilt angle was a more important factor across all speeds for the pendulum-based pedometer in the treadmill walking trials versus the accelerometry-based pedometer. The pendulum-based pedometer significantly underestimated steps at all treadmill speeds when the tilt angle was $> 10^\circ$. The accelerometry-based pedometer underestimated steps by 7% at the slowest speed and by 3% at the remaining speeds when the tilt angle was $> 15^\circ$. Therefore, the researchers concluded that an accelerometry-based pedometer should be utilized when monitoring the physical activity habits of the obese or overweight. However, this study was observational and did not systematically alter the tilt angle and, therefore, unable to differentiate between the effects of BMI and tilt angle on decreasing pedometer accuracy. Also, there was no reference provided for the degree measurements making it difficult to determine the specific points where the pedometers failed to maintain accurate step counts.

Summary

Pedometer validity is an important factor when choosing the optimal assessment tool. Understanding the potential obstacles that are presented with the use of pedometers is paramount. The consensus is with increasing BMI there is a decrease in pedometer accuracy. It has been further determined that this is not a linear relationship with BMI,

but attributable to the tilt angle associated with excess adiposity. However, the effect of tilt angle has not been studied in a methodical manner to determine the specific tilt angles where accelerometry- and pendulum-based pedometers fail to maintain accuracy.

CHAPTER 3

METHODOLOGY

Introduction

Pedometers are assessment tools frequently used to monitor the physical activity habits of the obese and overweight. However, there is a known association between increasing body mass index (BMI) and decreasing pedometer accuracy. The decrease in pedometer accuracy has been attributed to tilt angle, but the specific tilt angle where pedometers fail to maintain accuracy is unclear. Therefore, this study was designed to test two common mechanisms for pedometers, accelerometry- and pendulum-based, to determine the specific tilt angle where the pedometers fail to maintain step counts accurately.

Subjects

Twenty adult volunteers read and signed an informed consent document explaining the potential risks and benefits of participation in this study, as well as a Physical Activity Readiness Questionnaire (PAR-Q) to screen for physical limitations that would prevent them from participation in the study. Subjects were not considered overweight ($BMI < 25 \text{ kg/m}^2$) and had a waist-to-hip ratio categorized as low risk (females < 0.8 , males < 0.95) (ACSM, 2005) to limit the confounding effects of excess adiposity on pedometer accuracy.

Procedures

Subjects were required to visit the Montana State University Movement Science Laboratory twice within a two week period. During the initial visit, descriptive information was gathered on each subject including body height, weight, and age. Subjects were also familiarized with the treadmill protocol, specifically stepping on and off while the treadmill was in motion. Once comfortable with the treadmill protocol, subjects were fitted with a leather belt that provided a solid attachment surface for the pedometer gimbal. The pedometer gimbal (Figure 3.1) was a custom-built device used to alter the tilt angle of the pedometer around a medial-lateral or anterior-posterior axis. A gravity goniometer was used to verify each test angle. An angle of 0° on the pedometer gimbal was defined as parallel with gravity. Positive tilt angles indicated that the gimbal was rotated about a medial-lateral axis away from the subject, while negative tilt angles indicated a rotation toward the subject's body.

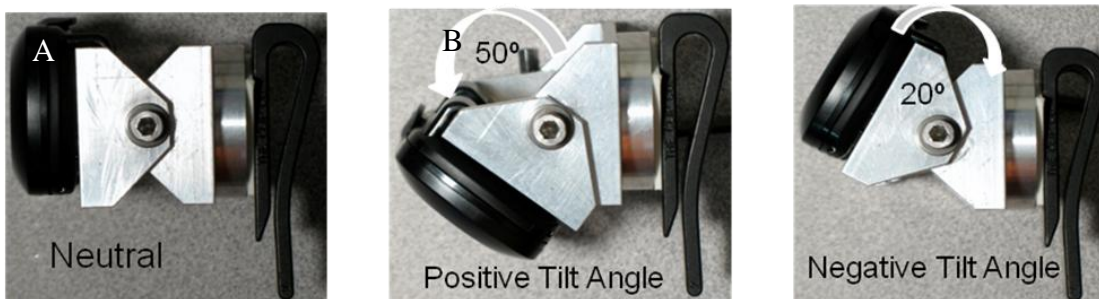


Figure 3.1. The pedometer gimbal was a custom-built instrument for systematically altering the tilt angle of the pedometer about a medial-lateral axis. This allowed the pedometer to be adjusted to a range of positions including: neutral (A) positive tilt (B) and negative tilt (C). The gimbal could be locked into place at the specified angle by tightening screws located on either side.

The testing protocol was the same for both lab visits. The particular type of pedometer worn, either accelerometry- or pendulum-based, was counterbalanced across subjects between the first and second visits. Pedometers were placed at each hip just anterior to the iliac crest and in line with the mid-axillary line of the thigh. A separate counterbalanced order was used to determine the hip (right or left) on which the control and experimental pedometers were worn. The pedometer gimbal was attached to the belt in the aforementioned location and adjusted to the appropriate tilt angle. The experimental pedometer was clipped to the pedometer gimbal and the control pedometer was attached to the belt in a neutral position ($\pm 2^\circ$ of zero).

Test Protocol

Subjects walked a total of 21 trials, each lasting 1.5 minutes, at a pre-selected combinations of treadmill speed (67.0, 80.4, 93.8 m/min, or 2.5, 3.0, 3.5 mph) and pedometer tilt angle (-30, -20, -10, 0, +10, +20, +30°). Both pedometer mechanisms have been validated as accurate at treadmill walking speeds ≥ 67.0 m/min (Le Masurier and Tudor-Locke, 2003). The tilt angles were chosen based on observations by Crouter et al. (2005) when testing obese populations. The authors found that the pendulum-based pedometer failed to maintain step counts accurately at $>10^\circ$, while the accelerometry-based pedometer failed to maintain accurate step counts at $>15^\circ$.

The first walking trial was used to verify step count accuracy between the control pedometer and the experimental pedometer attached to the gimbal set at 0° . Steps for both pedometers were compared to a hand tally used by an investigator. Once it was

determined that there were no deviations from the hand tally at any of the treadmill speeds, the hand tally was eliminated for the remaining trials. Acceptable accuracy between the hand tally and pedometers was defined as ± 2 steps. The remaining trials were tested in a counterbalanced order across subjects. Between trials, there was a thirty second rest interval for changing treadmill speed and recording pedometer steps.

Instrumentation

The Digiwalker® SW-200 (New Lifestyles, Inc., Lee's Summit, MO, USA) is a pendulum-based pedometer used to monitor physical activity. The step count is visible to the wearer by opening the face and viewing the digital readout. The pendulum-based pedometer has a suspended lever arm which operates in the frontal plane. According to the manufacturer, the Digiwalker® SW-200 is able to count up to 99,999 steps and should be placed on a belt or horizontal pocket with the clip against the body. The Digiwalker® SW-200 was found to be a valid assessment tool in both controlled and free-living settings (Schneider, Crouter, and Bassett, 2004; Crouter et al., 2003). Subjects wore two Digiwalker® SW-200s during one complete set of walking trials. Five new Digiwalker® SW-200s were used over the course of the study.

The New Lifestyles® NL 2000 (New Lifestyles, Inc., Lee's Summit, MO, USA) is an accelerometry-based pedometer and, in addition to counting steps, it monitors the intensity and duration of exercise. The New Lifestyles® NL 2000 allows for seven days of data storage, records calories and calculates basal metabolic rate (BMR). The New Lifestyles® NL 2000 was found to be a valid assessment tool in both controlled and free-

living settings for healthy individuals and special populations such as older adults (Crouter et al., 2003; Marsh et al., 2007). Subjects wore two New Lifestyles® NL 2000s during a complete set of walking trials. Five New Lifestyles® NL 2000 pedometers were used over the course of the study.

Subjects walked each trial on a True® 550 S.O.F.T. Select treadmill (Fitness Direct, San Diego, CA, USA). The treadmill speed was verified using a hand biddle tachrometer (AVO International, Blue Bell, PA, USA) during testing to monitor actual walking speeds. The treadmill has twelve soft select settings which control the firmness of the deck and was positioned at the firmest setting for all walking trials. Subjects' height and mass were recorded during each lab visit with a Health o Meter® PRO Series (Health o meter, Inc., Bridgeview, IL, USA) Balance Beam Scale to the nearest 0.1 cm and 0.1 kg, respectively.

Pedometer Data Analyses

The number of steps accumulated by each subject's control and experimental pedometers were converted into difference scores for subsequent analyses. Specifically, for each trial (i.e., combination of treadmill speed and pedometer tilt angle) the number of steps recorded by the experimental pedometer ($STEP_E$) was subtracted from the number of steps recorded by the control pedometer ($STEP_C$) to create a difference score ($\Delta STEP = STEP_C - STEP_E$). Mean $\Delta STEP$ values for both pendulum- and accelerometry-based pedometers were statistically compared using a 3-factor (treadmill speed x tilt angle x pedometer mechanism) repeated measures analysis of variance

(ANOVA). Post hoc comparisons included planned contrasts for mean Δ STEP values between pedometer mechanisms at each experimental trial (secondary hypothesis). In addition, a mean Δ STEP value with a 95% confidence interval that did not include zero was used to indicate that the experimental pedometer differed significantly from the control pedometer for each experimental trial (primary hypothesis). All statistical analyses were evaluated at the 0.05 alpha level.

Pilot Data Collection

A single subject completed pilot testing on September 19, 2007. There were no significant differences in steps between the control and experimental pedometers at any treadmill speed (67.0, 80.4, 93.8 m/min or 2.5, 3.0, 3.5 mph) for the 0°, ±10°, or ±20° tilt angle conditions (Figure 3.2). The pendulum-based pedometer began to lose accuracy at the slowest speed (67.0 m/min or 2.5 mph) at ±30°, but remained accurate at the faster speeds.

At the slowest speed combined with a ±30° tilt angle, the difference in steps between the control and the experimental pedometers was 36 steps (Δ STEP) at +30° and 15 steps at -30°. This would equate to a 2,236 and 974 step discrepancy for every 10,000 actual steps taken at 2.5 mph with the pedometer worn at a ±30° tilt angle. Once a tilt angle of ±40° was achieved, the pendulum-based pedometer was no longer accurate for any treadmill speed. The difference in steps ranged from 35 to 149 steps (Δ STEP) at ±40°, resulting in a practical difference of 1785 to 9675 step discrepancy for every 10,000 actually taken.

In summary, increasing tilt angles caused a decrease in pedometer accuracy. The negative tilt angles appeared to affect the step count accuracy less than the positive tilt angles, and the combination of slower speeds and increasing positive tilt angle tended to have the greatest impact on step count accuracy.

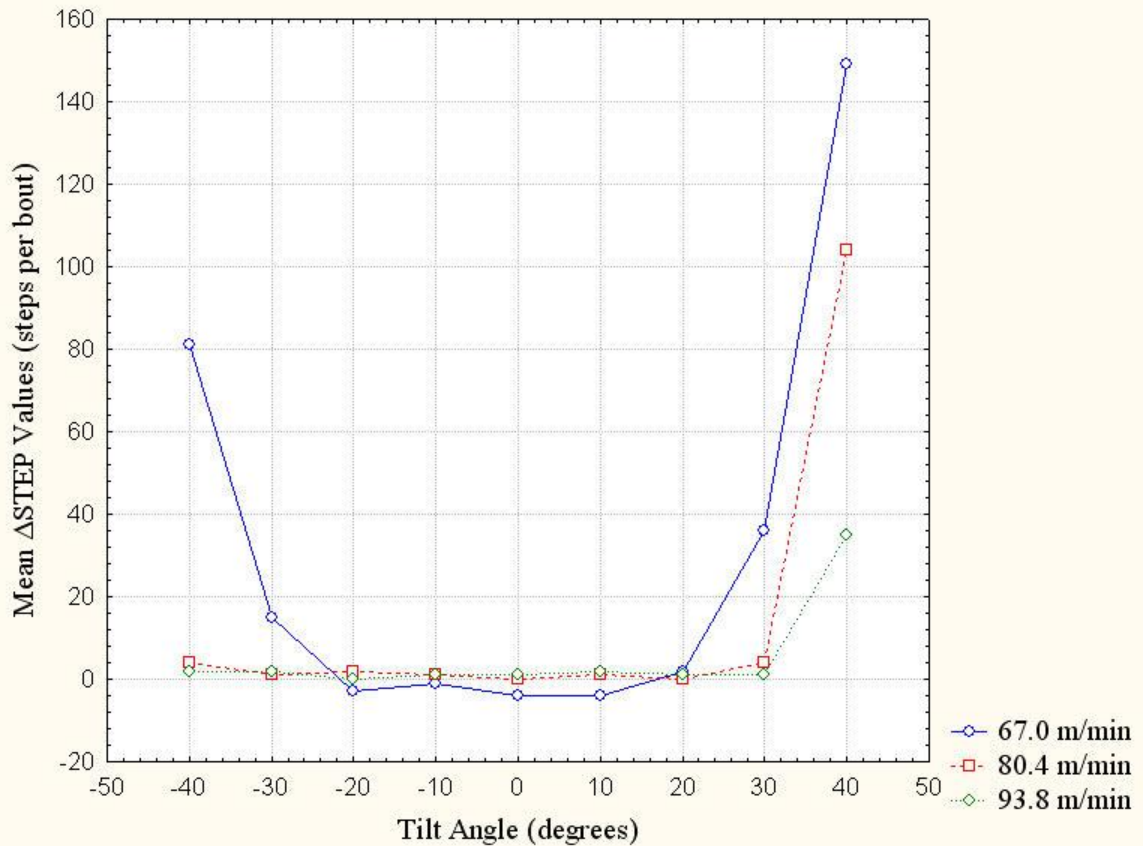


Figure 3.2. Δ STEP ($STEP_C - STEP_E$) versus tilt angle for a pendulum-based pedometer across all treadmill speeds. The solid line corresponds to data collected at a treadmill speed of 67.0 m/min (2.5 mph), the dashed line to 80.4 m/min (3.0 mph), and the dotted line corresponds to 93.8 m/min (3.5 mph). Positive tilt indicates the top of the pedometer is tilted away from the body while a negative tilt indicates a rotation towards the body.

CHAPTER FOUR

RESULTS

This study was designed to test the validity of two popular pedometer mechanisms, accelerometry- and pendulum-based, worn at altered tilt angles during controlled treadmill walking trials. The steps recorded by the experimental pedometer ($STEP_E$) were subtracted from the steps recorded by the control pedometer ($STEP_C$) to calculate a difference score ($\Delta STEP = STEP_C - STEP_E$) for each trial. Mean $\Delta STEP$ values were calculated for all trials for both the accelerometry- and pendulum-based pedometers. The independent variables of interest were pedometer mechanism, treadmill walking speed and tilt angle, while the dependent variable was steps.

Twenty-one subjects completed the treadmill walking protocol using both pedometer mechanisms in two separate visits to the Montana State University Movement Science Lab. However, only data from twenty subjects was analyzed. Data from one female subject (S09) was not analyzed due to unexpectedly high step counts from the experimental pedometer. Further testing determined that the pedometer was malfunctioning and, therefore, the data from this subject was omitted from analysis and the pedometer was not used for future testing. All subsequent analyses were performed on data from the remaining twenty subjects (10 women, 10 men).

All subjects had a body mass index (BMI) $< 25.0 \text{ kg/m}^2$ (Table 4.1), which is considered “normal”, or below the classification for overweight and obese individuals (BMI $\geq 25 \text{ kg/m}^2$). Subjects were also classified as low risk for chronic diseases as

determined by their waist to hip ratio, which for males is < 0.95 and for females < 0.8 (ACSM, 2005). Therefore, subjects were not considered overweight, and pedometers have been verified as accurate in normal weight populations for controlled treadmill walking trials (Le Masurier and Tudor-Locke, 2003).

Table 4.1. Subject demographics presented as Mean \pm SD (range). All subjects had a body mass index (BMI) < 25.0 kg/m² and were not considered overweight.

Subjects	Age (yrs)	Body Height (cm)	Body Weight (kg)	BMI (kg/m ²)	Waist to Hip Ratio
Women (n=10)	21.6 \pm 3.0 (18-27)	166.1 \pm 6.3 (153.7-175)	56.7 \pm 6.7 (46.9-70.7)	20.5 \pm 1.8 (17.2-22.1)	0.67 \pm 0.08 (0.6-0.74)
Men (n=10)	26 \pm 4.5 (19-33)	182.7 \pm 5.3 (178.5-192.7)	75.7 \pm 5.4 (67.1-85.5)	22.7 \pm 1.6 (20.5-24.8)	0.81 \pm 0.1 (0.72-0.93)

The primary purpose of this study was to determine the specific tilt angles where either pedometer mechanism was no longer counting steps accurately. To determine the tilt angles that caused either pedometer mechanism to record steps inaccurately, the mean Δ STEP values for both the pendulum- and accelerometry- based pedometers were compared to zero. For the present study, an accurate step count was defined as a non-significant difference between Δ STEP and zero. The pendulum- and accelerometry-based pedometers were accurate at 0° tilt across all treadmill speeds eliminating the pedometer gimbal as a potential source of variation in steps (Table 4.2, Table 4.3).

In general, the accelerometry- and pendulum-based pedometers decreased in accuracy with increasing tilt angle in either direction (Figure 4.3). In all cases, a decrease in pedometer accuracy was equivalent to increases in mean Δ STEP values due to STEP_E

counting fewer steps compared to $STEP_C$. Fewer steps were counted by $STEP_E$ with increasing positive tilt angles versus negative tilt angles for both pedometer mechanisms. A decrease in treadmill speed also caused higher mean $\Delta STEP$ values, and the combination of decreasing treadmill speed and increasing positive tilt angle caused the greatest increases in mean $\Delta STEP$ values. However, $\Delta STEPs$ for the pendulum-based pedometer was significantly different from the control pedometer when the tilt angle was equal to $+10^\circ$ and the treadmill speed was ≤ 80.4 m/min, but still accurate at 93.8 m/min. Once the tilt angle was increased to $+20^\circ$, the pendulum-based pedometer was not significantly different from zero at 80.4 m/min. However, the standard error for this trial was relatively large (5.6 ± 3.1 steps) and the 95% confidence interval was -0.8 to 12 steps. Therefore, the large variations in $\Delta STEP$ values was probably due to gait variations of the individuals, specifically subjects fifteen and twelve (S15, S12). These subjects recorded more steps with the experimental pedometer compared to other trials ($\Delta STEP$ equals -9 and -11 steps, respectively).

Table 4.2. Mean Δ STEP values \pm SE and 95% confidence intervals for the pendulum-based pedometer across all treadmill speeds and tilt angles. Mean Δ STEP equals steps for the control pedometer (STEP_C) – steps for the experimental pedometer (STEP_E).

Tilt Angle (Degrees) for the pendulum-based pedometer							
Treadmill Speed	-30°	-20°	-10°	0°	+10°	+20°	+30°
67.0 m/min (2.5 mph)	19.6 \pm 4.1*§ (11.1-28.1)	7.3 \pm 2*§ (3.1-11.4)	12.5 \pm 3.2*§ (5.8-19.1)	-0.5 \pm 0.5 (-1.5-0.6)	10.5 \pm 4.7*§ (0.6-20.3)	10.8 \pm 2.8*§ (4.8-16.8)	46.1 \pm 6.9*§ (31.6-60.6)
80.4 m/min (3.0 mph)	9.4 \pm 2.4*§ (4.3-14.5)	3.8 \pm 0.8*§ (2-5.5)	5.0 \pm 1.9*§ (1.0-8.9)	0.1 \pm 0.5 (-1.0-1.0)	2.4 \pm 0.9*§ (0.6-4.2)	5.6 \pm 3.1§ (-0.8-12.0)	31.2 \pm 7.6*§ (15.3-47)
93.8 m/min (3.5 mph)	5.1 \pm 1.8*§ (1.3-8.7)	2.8 \pm 0.8§ (-0.7-2.9)	2.1 \pm .9*§ (0.1-4.1)	-0.7 \pm 0.5 (-1.6-0.3)	1.3 \pm 0.8§ (-0.4-2.9)	1.4 \pm 0.5*§ (0.4-2.4)	18.1 \pm 5.8*§ (5.9-30.2)

* denotes significantly Δ STEP values compared to zero (P < 0.05).

§ denotes significant difference between pedometer mechanisms for given tilt angle and treadmill speed (P < 0.05).

Table 4.3. Mean Δ STEP values \pm SE and 95% confidence intervals for the accelerometry-based pedometer across all speeds and tilt angles. Mean Δ STEP equals steps for the control pedometer (STEP_C) – steps for the experimental pedometer (STEP_E).

Tilt Angle (Degrees) for the accelerometry-based pedometer							
Treadmill Speed	-30°	-20°	-10°	0°	+10°	+20°	+30°
67.0 m/min (2.5 mph)	7.4 \pm 2.0*§ (3.4-11.3)	6.4 \pm 2.1*§ (1.9-10.8)	5.0 \pm 1.2*§ (2.4-7.5)	-0.3 \pm 0.3 (-1.0-0.5)	7.0 \pm 2.0*§ (3.0-10.9)	7.1 \pm 3.3*§ (3.1-11.0)	13.2 \pm 5.0*§ (2.6-23.7)
80.4 m/min (3.0 mph)	5.3 \pm 2.0*§ (1.3-9.3)	1.3 \pm 0.7§ (-0.1-2.7)	1.7 \pm 2.2§ (-2.3-5.6)	0.5 \pm 0.3 (-0.2-1.2)	2.6 \pm 2.0§ (-1.4-6.6)	4.1 \pm 1.9*§ (0.2-8.0)	6.8 \pm 2.3*§ (1.9-11.7)
93.8 m/min (3.5 mph)	4.3 \pm 2.0*§ (0.3-8.3)	0.9 \pm 0.6§ (-0.3-2.1)	1.9 \pm 2.0§ (-2.1-5.8)	0.0 \pm 0.3 (-0.6-0.6)	3.2 \pm 2.0§ (-0.8-7.1)	2.2 \pm 2.0§ (-1.8-6.1)	2.2 \pm 0.6*§ (0.8-3.5)

* denotes significantly higher Δ STEP values compared to zero (P < 0.05).

§ denotes significant difference between pedometer mechanisms for given combination of tilt angle and treadmill speed (P < 0.05).

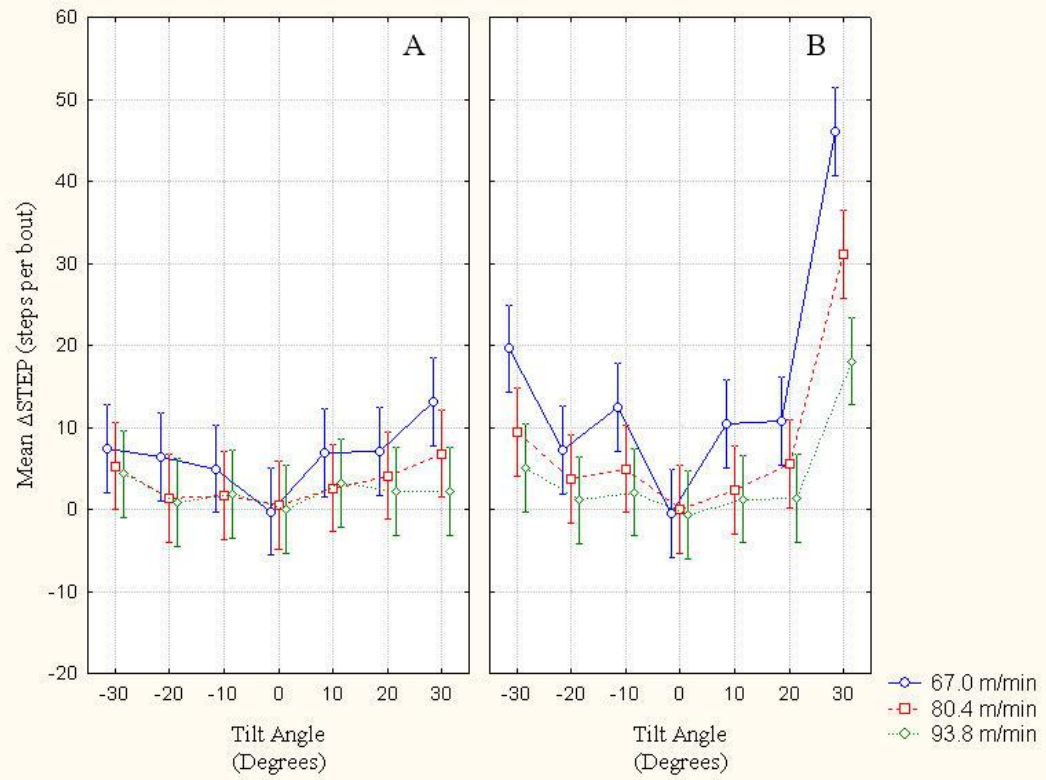


Figure 4.3. Mean ΔSTEP ($\text{STEP}_E - \text{STEP}_C$) values for both the accelerometry- (A) and pendulum- based (B) pedometers at three treadmill speeds (67.0, 80.4, 93.8 m/min) and seven tilt angles (0° , $\pm 10^\circ$, $\pm 20^\circ$, $\pm 30^\circ$). Mean ΔSTEP values are expressed as the standard error per tilt angle and treadmill speed, with the bars representing the 95% confidence interval. Note: STEP_E and STEP_C are the total steps recorded by the experimental and control pedometers, respectively.

The pendulum-based pedometer was not accurate at any speed when tilt angle was increased beyond -10° . However, ΔSTEP s for the pendulum-based pedometer were not significantly different from the control pedometer when the tilt angle was equal to -20° and treadmill speed was 93.8 m/min. The standard error for this trial was high (2.8 ± 0.8 steps) and the 95% confidence interval was -0.7 steps to 2.9 steps, with several subjects recording higher steps with the experimental pedometer compared to other trials.

Specifically, subjects 5 and 10 recorded higher steps with the experimental pedometer compared to other trials (Δ STEP equals -13 and -9 steps, respectively).

For all four of the previous subjects, the anomalous trial was either the first (S10, S15) or last trial (S05, S12) of the particular testing day. While all subjects were familiarized with walking on the treadmill, these particular subjects (S10, S15) may have needed more time despite reporting that they were comfortable and adequately warmed up. While subjects 5 and 12 did not report any fatigue, there may have been fatigue related changes in gait which resulted in higher Δ STEP values for this trial.

The accelerometry-based pedometer did not maintain accurate step counting at tilt angles $\geq \pm 10^\circ$ when treadmill speed was equal to 67.0 m/min. As treadmill speed increased to 80.4 m/min, the accelerometry-based pedometer was no longer accurate at tilt angles $> +20^\circ$ and at -30° . A treadmill speed of 93.8 m/min resulted in significant differences from the control at $\pm 30^\circ$.

For both types of pedometers, within any given tilt angle, the 67.0 m/min treadmill speed resulted in a significantly higher Δ STEPS when compared to the 93.8 m/min speed. However, the 80.4 m/min condition was not significantly different from either the 67.0 or 93.8 m/min conditions.

The secondary purpose of this study was to determine if one pedometer mechanism, accelerometry- or pendulum-based, responded differently to changing tilt angle. In order to determine if one pedometer mechanism was more accurate for any given combination of treadmill speed and tilt angle, mean Δ STEP values were compared between pedometer mechanisms for the same previously determined combinations of tilt

angle and treadmill speed. Decreasing treadmill speed and increasing tilt angle in either direction caused increases in mean Δ STEP values for both pedometer mechanisms. However, the accelerometry-based pedometers were less affected by speed and tilt angle than the pendulum-based pedometer. For example, when tilt angle was $\geq \pm 10^\circ$, the accelerometry-based pedometers were significantly different than the pendulum-based pedometers across all treadmill speeds (Table 4.2, Table 4.3). The $STEP_E$ values for the pendulum-based pedometer were lower compared to the $STEP_E$ values for the accelerometry-based pedometer at the same tilt angles and treadmill speeds, causing greater increases in mean Δ STEP values for the pendulum-based pedometer compared to the accelerometry-based pedometer.

At a 0° tilt, both the accelerometry- and pendulum-based pedometers had mean Δ STEP values within one step of zero. When tilt angle increased to $\pm 10^\circ$, the pendulum-based pedometer had significantly higher Δ STEP values compared to the accelerometry-based pedometer (2 to 13 steps versus 1 to 7 steps, respectively). As tilt angle increased beyond $\pm 10^\circ$, the pendulum-based pedometer continued to record higher mean Δ STEP values than the accelerometry-based pedometer.

Summary

The primary purpose of this study was to determine the tilt angles where both pedometer mechanisms no longer maintained accurate step counts, where accuracy was defined as a non-significant difference between Δ STEP and zero. The pendulum-based pedometer did not count steps accurately when the tilt angle was $\geq +10^\circ$ and treadmill

speed was < 93.8 m/min. The pendulum-based pedometer was not accurate at any treadmill speed when tilt angle increased to $+30^\circ$. When the pendulum-based pedometer was rotated in the posterior direction, it was not accurate at any treadmill speed when tilt angle was $\geq -10^\circ$.

Mean Δ STEPS for the accelerometry-based pedometer was significantly greater than zero at all tilt angles when the treadmill speed was equal to 67.0 m/min, and was not accurate at any treadmill speed when tilt angle increased to $\pm 30^\circ$. The pendulum-based pedometers had larger increases in mean Δ STEP values compared to the accelerometry-based pedometers for all test conditions.

Both pedometer mechanisms decreased in accuracy with increasing tilt angle in either direction. Positive tilt angles caused more extreme deviations in step counting accuracy, or higher mean Δ STEP values, than negative tilt angles, and the combination of decreasing treadmill speed and increasing tilt angle in either direction had the greatest impact on step counting accuracy.

CHAPTER 5

DISCUSSION

Introduction

Researchers have tested the validity and reliability of popular pendulum- and accelerometry-based pedometers in controlled treadmill walking and free-living studies (Troost et al, 2000; Le Masurier and Tudor-Locke, 2003; Matthew, 2005; Freedson, Pober and Janz, 2005). Additionally, many researchers have observed decreasing pedometer accuracy with increasing body mass index (BMI) (Sheperd et al.,1999; Crouter et al., 2005). However, these studies have not been able to identify the specific cause of the decrease in pedometer accuracy with increases in BMI. The study conducted by Crouter, et al. (2005) first identified tilt angle as the possible source of error. However, this study was observational and therefore, the extent that tilt angle affects pedometer accuracy remains unclear.

Study Design

The present study was the first to systematically alter pedometer tilt angle to mimic changes that occur in overweight and obese populations. By using a custom-built pedometer gimbal, decreasing pedometer accuracy was related to changes in tilt angle because the confounding influence of excess abdominal adiposity was removed. All subjects tested had a BMI < 25 kg/m², which is below the criterion for overweight or obese , and were classified as low risk for waist-to-hip ratio (males < 0.95, females < 0.5)

(ACSM, 2005). Also, the pedometer gimbal was tested in a neutral position ($\pm 2^\circ$ of 0° , or perpendicular to the ground) prior to testing of the experimental angles to ensure that the pedometer gimbal was not a source of error.

Acceptable accuracy for pedometers has been established for controlled treadmill walking trials and free-living studies as 3% and 10%, respectively (Crouter et al., 2003). The treadmill speeds tested in the present study (67.0, 80.4 and 93.8 m/min) were chosen because both pedometer mechanisms have been verified as accurate at treadmill walking speeds ≥ 67.0 m/min in normal weight populations (Le Masurier and Tudor-Locke, 2003). While decreasing treadmill speed caused amplified deviations in pedometer accuracy, treadmill speed alone did not cause the decrease in accuracy. The tilt angles where the pendulum- and accelerometry-based pedometers lost accuracy ($\pm 10^\circ$ for the pendulum, ± 10 to $\pm 20^\circ$ for the accelerometer) were similar to those reported by Crouter et al. (2005) ($\pm 10^\circ$ for the pendulum, $\pm 15^\circ$ for the accelerometry). However, it is important to note that the latter study was observational and could not distinguish between the affects of BMI versus tilt angle.

Causes of Pedometer Inaccuracies

Both pedometer mechanisms decreased in accuracy with increasing tilt angle in either direction. When tilt angle was equal to 0° , neither pedometer mechanism was significantly different from zero at any treadmill speed. Non-significant deviations were a result of the pedometer oriented in line with the ground reaction force (GRF) vector. This orientation allowed sufficient transmission of force in line with the lever arm of the

pendulum-based pedometer causing it to overcome friction and inertia to swing and count a step. In the case of the accelerometry-based pedometer, sufficient force was transmitted in line with the piezoelectric element to cause it to deflect and count a step. Because both of the pedometers tested are sensitive in only one plane, they were affected by tilt angle. When tilt angle was increased beyond 0° for either pedometer mechanism, the vector components of the ground reaction force parallel to the plane of motion were reduced. Additionally, because of the moving parts inherent to the pendulum-based pedometer, friction was increased as the mechanism was tilted. The result of each of these conditions was a decreased probability that the mechanisms deflected accurately. Treadmill speed affected the mechanisms in a similar manner. An increase in treadmill speed caused a larger GRF which also increased the component vectors parallel with the pedometer mechanisms. At slower treadmill speeds, the magnitude of the GRF is decreased; leading to further reduction of the component vectors inline with the mechanism and a decreased probability of an accurate count. However, for the present study, treadmill speed did not independently contribute to pedometer accuracy. For example, at a 0° tilt angle, both pedometer mechanisms were accurate at all treadmill speeds. As tilt angle increased to $+10^\circ$, mean Δ STEP values were higher for both pedometer mechanisms at the 67.0 m/min treadmill speed compared to the 80.4 or 93.8 m/min treadmill speeds.

Sources of Variation

Overall, variations in steps between pedometer mechanisms and between the experimental pedometer and the control were directly attributable to the changes in tilt

angle. However, the interaction between tilt angle and treadmill walking speed caused increases in Δ STEP values for all tilt angles as treadmill speed decreased. For example, mean Δ STEPS for the pendulum-based pedometer at $+30^\circ$ was 46.1 steps at 67.0 m/min, but decreased to 18.1 steps at 93.8 m/min.

There were some variations between individuals per tilt angle and speed which was most notable at the $\pm 20^\circ$ tilt angle for both pedometer mechanisms. In a recent study, researchers found that decreasing pedometer accuracy may be a result of normal gait asymmetry, which is specific to the individual (Horvath, Taylor, Marsh and Kriellaars, 2007). The researchers found that decreasing pedometer accuracy for individual subjects occurred when the pedometer was worn at the mid thigh position on the dominant leg. However, it must be noted that decreases in pedometer accuracy were specific to the individual. Also, speeds used were slower than used in the present study (54.0 m/min versus 67.0 m/min) and speeds < 67.0 m/min have not been found to be accurate in other pedometer studies (Crouter et al., 2003; Schneider et al., 2003). Goble, Marino and Potvin (2003) found gait asymmetries were greater at slower velocities and trended towards improved symmetry at higher velocities. However, the relative speeds (slow, moderate, and fast) were chosen by the subjects and did not find significant evidence to invalidate the use of symmetry assumptions. The present study used a counter balanced order for determining the hip location (right versus left) for placement of the experimental and control pedometers to minimize the effect of individual gait variations. Future studies should take this into consideration and potentially have subjects wear pedometers on both hips to minimize the effect of individual gait variations on the

results.

Implications for Future Pedometer Use

Many researchers use pedometers as part of physical activity interventions or to monitor walking related physical activity in overweight and obese populations. These studies often focus on increasing steps with a goal of achieving at least 10,000 steps per day, which is the equivalent of meeting the US Surgeon General's recommendation to accumulate 30 minutes of activity on most if not all days of the week (USDHHS, 1996). This goal allows individuals to make moderate lifestyle changes to meet the physical activity guidelines and pedometers provide an objective way for researchers to evaluate physical activity habits.

However, pedometer accuracy can become an issue if an individual is wearing the pedometer at an altered tilt angle. Acceptable accuracy standards have been established for controlled treadmill walking trials and free-living studies as 3% and 10%, respectively (Crouter et al., 2003). However, if an individual is wearing a pedometer at an altered tilt angle due to incorrect wear position or excess abdominal adiposity, this can result in the pedometer recording fewer steps than actually taken, and fall below the line of acceptable accuracy.

In the present study, the predicted recorded steps were calculated for all trials by taking the average of the steps per trial, determining the difference in steps for the experimental pedometer, and extrapolating to 10,000 steps. For the pendulum-based pedometer, the predicted recorded steps for every 10,000 steps actually taken ranged

from 9,953 steps at a 0° tilt to 7100 steps at a +30° tilt (Figure 5.4). The difference in steps is equivalent to a .05% and 29% difference, respectively. At a ±10° tilt angle, the pendulum- based pedometer exceeded the established 3% standard for acceptable accuracy at the 67.0 m/min treadmill speed, recording only 9,300 and 9,100 steps for every 10,000 actually taken (7% and 9% difference, respectively).

For the accelerometry- based pedometer, the predicted recorded steps for every 10,000 actual steps taken ranged from no difference at a 0° tilt to a predicted recorded 8,300 steps at +30° and 67.0 m/min (17% difference) (Figure 5.5). The accelerometry- based pedometer did not meet the standard for acceptable accuracy at ±10° and 67.0 m/min, but only deviated by 3.8% and 5%, respectively.

The accelerometry- and pendulum- based pedometer did not meet the standard for acceptable accuracy at ±10° for treadmill speeds < 67.0 m/min and 93.8 m/min, respectively. Future research should take these findings into consideration when choosing an assessment tool, especially if the velocity of the subject cannot be controlled such as is the case with free living studies.

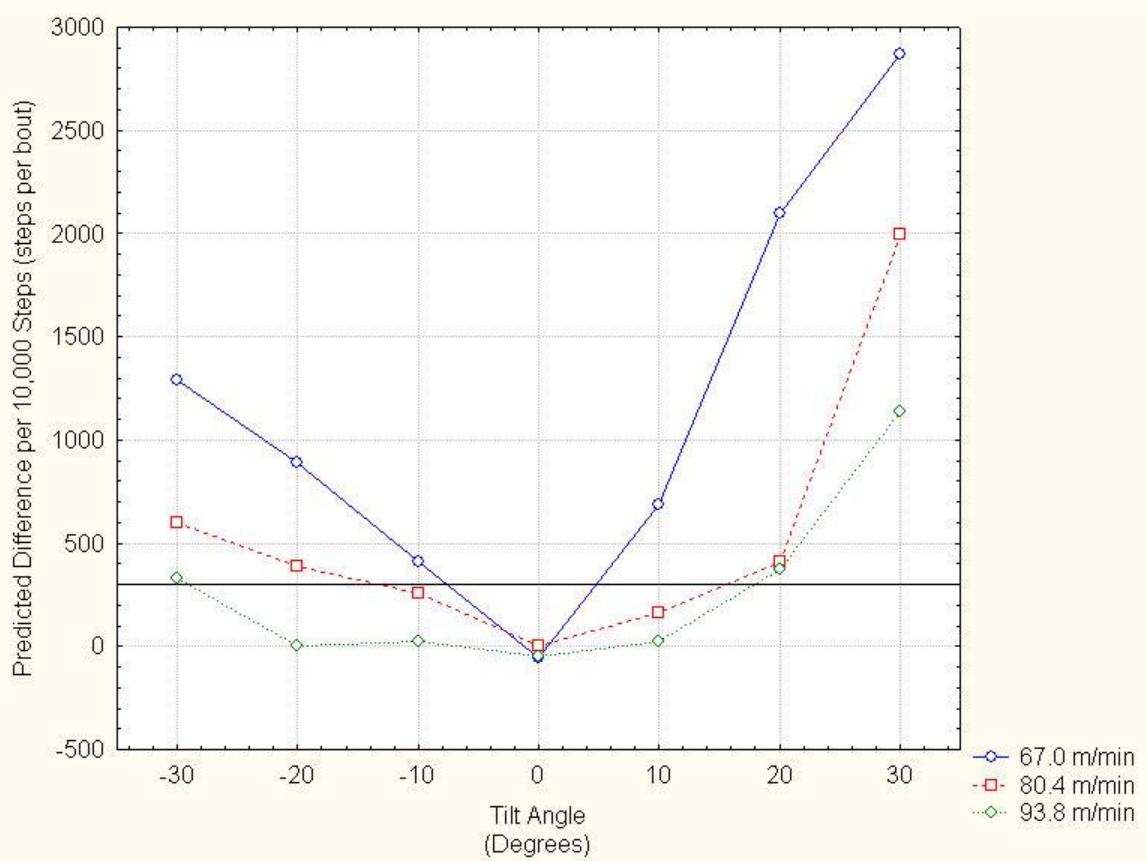


Figure 5.4. Predicted recorded steps for the pendulum-based pedometer for every 10,000 steps actually taken based on deviations in mean Δ STEP values. Each line corresponds to data collected per treadmill speed at each tilt angle. The solid line at 300 steps represents the 3% standard for acceptable accuracy. Data points above this line have exceeded the standard, and the pendulum-based pedometer cannot be considered accurate at these treadmill speeds and tilt angles.

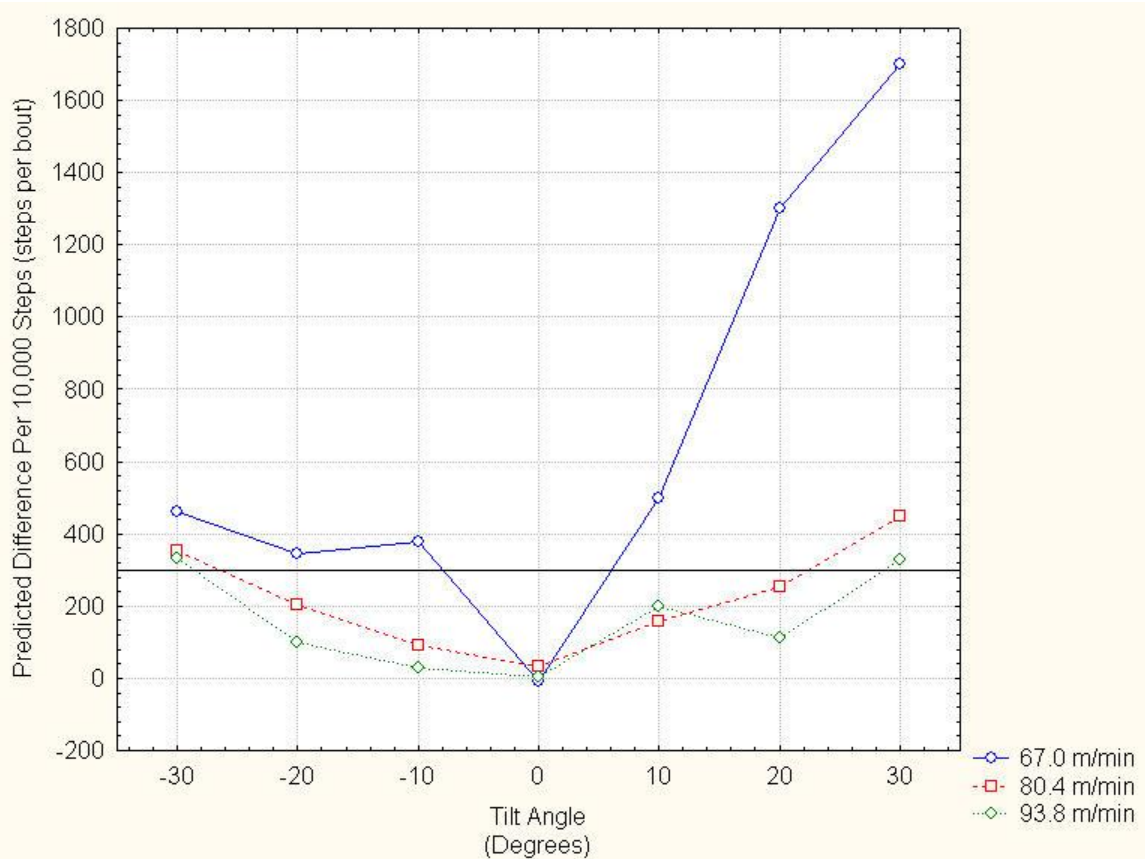


Figure 5.5. Predicted recorded steps for the accelerometry-based pedometer for every 10,000 steps actually taken based on deviations in mean Δ STEP values. Each line corresponds to data collected per treadmill speed at each tilt angle. The solid line at 300 steps represents the 3% standard for acceptable accuracy. Data points above this line have exceeded the standard, and the accelerometry-based pedometer cannot be considered accurate at these treadmill speeds and tilt angles.

Summary

A pedometer worn at an altered tilt angle caused it to record fewer steps than the control pedometer. The deviations in step counting accuracy were influenced by treadmill speed, although were not caused by decreasing speed. The accelerometry-based pedometers continued to record steps accurately at tilt angles greater than the pendulum-based pedometer.

Researchers using a pedometer to objectively measure physical activity should be aware of decreasing pedometer accuracy due to tilt angle. An individual at an altered tilt angle can record significantly fewer steps than actually taken, and the more severe the tilt, the fewer steps will be recorded.

CHAPTER SIX

CONCLUSIONS

Pedometers are tools that are frequently utilized to objectively measure walking related physical activity of overweight and obese populations. However, pedometer validity is known to decrease with increasing body mass index (BMI), which has been attributed to tilt angle.

The present study found that the accuracy of both pedometer mechanisms, accelerometry- and pendulum-based, decreased with increasing tilt angle in either direction. At a relatively minor tilt of $\pm 10^\circ$, both the accelerometry- and pendulum-based pedometers recorded fewer steps than the control. Decreasing treadmill speed combined with increasing tilt angle caused the greatest deviations for both pedometer mechanisms.

Due to the relationship between increasing tilt angle and decreasing pedometer accuracy, researchers using pedometers to assess physical activity should take the following recommendations into consideration: a tilt angle $< \pm 10^\circ$ does not require any special considerations. An absolute tilt angle between $\pm 10^\circ$ and $\pm 20^\circ$ can be assumed to be acceptably accurate if an accelerometry-based pedometer is used and speed is controlled. In cases where speed is not being controlled, such as free-living studies, or if tilt angle is $\geq \pm 20^\circ$, the accelerometry- and pendulum-based pedometers can no longer be assumed to be accurate. In these instances a different attachment site should be sought where the pedometer can lie in a more neutral position (parallel with gravity), such as the ankle or lower back, or a different assessment tool should be used.

Further research is warranted to verify the inaccuracies that occur with increasing tilt angle versus BMI. Replicating the design of the present study using overweight and obese individuals will help isolate the effects of excess adiposity on pedometer accuracy. This information will aid the researcher in choosing an appropriate assessment tool when recording physical activity patterns in special populations.

Many individuals use pedometers to gauge progress towards physical activity goals, which is an important motivational factor. Participants who are increasing steps but not meeting the established guidelines due to decreasing pedometer accuracy are at risk of attrition to a physical activity program. Therefore, individuals using pedometers to measure walking related physical activity as part of a personal fitness plan or intervention should be made aware of potential discrepancies in step counts with increasing tilt angle.

REFERENCES

- American College of Sports Medicine. (2005). *ACSM's Guidelines for Exercise Testing and Prescription*. New York: Lippincott Williams & Wilkins.
- Bassett, D.R. Jr., Ainsworth, B.E., Leggett, C.A., Main, J.A., Hunter, D.C., & Duncan, G.E. (1996). Accuracy of five electronic pedometers for measuring distance walked. *Medicine and Science in Sports and Exercise*, 28, 1071-1077.
- Crouter, S.E., Schneider, P.L., Karabulut, M., & Bassett, D.R. Jr. (2003). Validity of 10 electronic pedometers for measuring steps, distance, and energy cost. *Medicine and Science in Sports and Exercise*, 35, 1455-1460.
- Crouter, S.E., Schneider, P.L., & Bassett, D.R. Jr. (2005). Spring-levered versus piezo electric pedometer accuracy in overweight and obese adults. *Medicine and Science in Sports and Exercise*, 37, 1673-1679.
- Davis, M.G., & Fox, K.R. (2006). Physical activity patterns assessed by accelerometry in older people. *European Journal of Applied Physiology*, 10.1007, 421-429.
- Esliger, D.W., Probert, A., Gorber, S.C., Bryan, S., Laviolette, M., & Tremblay, M.S. (2007). Validity of the Actical accelerometer step-count function. *Medicine and Science in Sports and Exercise*, 39, 1200-1204.
- Felton, G.M., Tudor-Locke, C., & Burkett, L. (2006). Reliability of pedometer determined free-living physical activity data in college women. *Research Quarterly for Exercise and Sport*, 77, 304-308.
- Freedson, P.S., Pober, D., & Janz, K.F. (2005). Calibration of accelerometer output for Children. *Medicine and Science in Sports and Exercise*, 37, 523-530.
- Gerwin, A., Meijer, K.R., Westerterp, H.K., Koper, H., & Hoor, F.T. (1989). Assessment of energy expenditure by recording heart rate and body acceleration. *Medicine and Science in Sports and Exercise*, 21, 343-347.
- Goble, D.J., Marino, G.W., & Potvin, J.R. (2003). The influence of horizontal velocity on interlimb symmetry in normal walking. *Human Movement Science*, 22, 271-283).
- Horvath, S., Taylor, D.G., Marsh, J.P., & Kreillaars, D.J. (2007). The effect of pedometer position and normal gait asymmetry on step counting accuracy. *Applied Physiology and Nutrition Metabolism*, 32, 409-415.
- LaPorte, R.E., Montoye, H.J., & Casperson, C.J. (1985). Assessment of physical activity in epidemiologic research: problems and prospects. *U.S. Department of Health and Human Services; Public Health Reports*, 100, 131-146.

- LeMasurier, G.C., & Tudor-Locke, C. (2003). Comparison of Pedometer and accelerometer accuracy under controlled conditions. *Medicine and Science in Sports and Exercise*, 35, 867-871.
- Marsh, A.P., Vance, R.M., Frederick, T.L., Hesselmann, S.A., & Rejeski, J.W. (2007). Objective assessment of activity in older adults at risk for mobility disability. *Medicine and Science in Sports and Exercise*, 39, 1020-1026.
- Matthew, C.E. (2005). Calibration of accelerometer output for adults. *Medicine and Science in Sports and Exercise*, 37, 512-522.
- McArdle, W.D, Katch, F.I., & Katch, V.I. (1991). Energy transfer in exercise. *Exercise Physiology: Exercise, Nutrition and Human Performance*, 123-144.
- Meijer, G.A., Westerterp, K.R., Koper, H., & Ten Hoor, F. (1989). Assessment of energy expenditure by recording heart rate and body acceleration. *Medicine and Science in Sports and Exercise*, 21, 343-347.
- National Center for Health Statistics. (2004). *Obesity still a major problem, new data show*. [News Release]. Retrieved October 20, 2006, from <http://www.cdc.gov/nchs/pressroom/04facts/obesity.htm>.
- Pate, R.R., Pratt, M., Blair, S.N., Haskell, W. L., Macera, C. A., Bouchard, C., et al. (1995). Physical activity and public health: A recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine. *Journal of the American Medical Association*, 273, 402-407.
- Schneider, P. L., Crouter, S.E., & Bassett, D.R. Jr. (2004). Pedometer Measures of Free Living Physical Activity: Comparison of 13 Models. *Medicine & Science in Sports and Exercise*, 36, 331-335.
- Schneider, P.L., Crouter, S.E., Lukajic, O., & Bassett, D.R. Jr. (2003). Accuracy and reliability of 10 pedometers for measuring steps over a 400-meter walk. *Medicine and Science in Sports and Exercise*, 35, 1673-1679.
- Shepherd, E., Toloza, E., McClung, C., & Schalzried, T. (1999). Step activity monitor: increased accuracy of quantifying ambulatory activity. *Journal of Orthopaedic Research*, 17, 703-708.
- Swartz, A.M., Strath, S.J., Bassett, D.R., O'Brien, W.L., King, G.A., & Ainsworth, B.E. (2000). Estimation of energy expenditure using CSA accelerometers at hip and wrist sites. *Medicine & Science in Sports & Exercise*, 32, S450-S456.

- Torgan, C. (June 2002). Childhood obesity on the rise. *NIH Word on Health*, Retrieved October 20, 2006, from <http://www.nih.gov/news/WordonHealth/jun2002/childhoodobesity.htm>.
- Trost, S.G., McIver, K.L., & Pate, R.R. (2005). Conducting accelerometer-based activity assessments in field-based research. *Medicine & Science in Sports and Exercise*, 37, 531-543.
- Tudore-Locke, C., Ainsworth, B.E., Thompson, W.W., & Matthews, E. (2002). Comparison of pedometer and accelerometer measures of free-living physical activity. *Medicine and Science in Sports and Exercise*, 34, 2045-2051.
- U.S. Department of Health and Human Services. (1996). *Physical activity and health: A report of the surgeon general*. (DHHS publication No. 1). Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion.
- World Health Organization. (2003). *Obesity and Overweight; Global Strategy on Diet Physical Activity and Health*. [News Release]. Retrieved October 10, 2007 from <http://www.who.int/dietphysicalactivity.htm>

APPENDICES

APPENDIX A

SUBJECT CONSENT FORM

**SUBJECT CONSENT FORM
FOR PARTICIPATION IN HUMAN RESEARCH
MONTANA STATE UNIVERSITY**

PROJECT TITLE: *Influence of Pedometer Tilt Angle on Step Counting Validity during Controlled Treadmill Walking Trials*

PROJECT DIRECTOR: Melissa Dock, Graduate Student
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FUNDING: This project is not funded

PURPOSE OF THE STUDY:

The purpose of this project is to examine the relationship between pedometer tilt angle and step count accuracy. Each subject will walk on a treadmill while wearing a belt fitted with two pedometers; one attached to a pedometer gimbal and the other worn normally. A pedometer is a device which counts steps and is frequently used to monitor walking related activity. A pedometer gimbal is an instrument built for the purpose of altering the tilt angle of a pedometer about a medial-lateral axis (fore/aft tilt) or anterior-posterior axis (left/right tilt) (Figure 1). Pedometer tilt angle refers to the fore and aft tilt of a pedometer that deviates from a degree of zero as measured with respect to gravity. The goal of this project is to determine the specific angles where the pedometers fail to maintain accuracy and determine if a particular pedometer mechanism maintains accuracy better. The findings could provide useful information to researchers collecting data on obese or overweight populations, companies who make such products, and you, as a potential user of pedometer technologies.

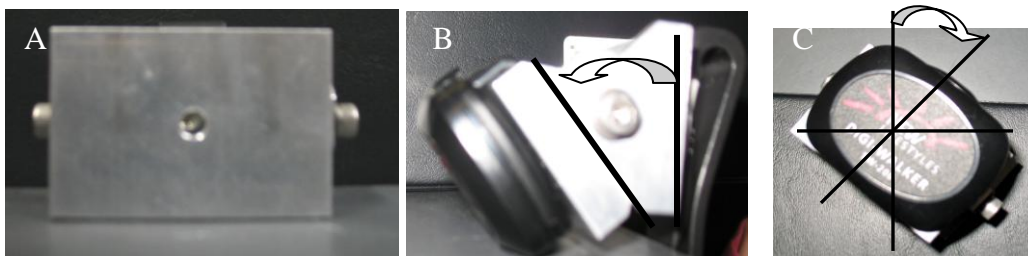


Figure 1: The pedometer gimbal (A) was an instrument for systematically altering the tilt angle of the pedometer fore and aft (B) or left and right (C). Only fore and aft tilt angles are being tested during this study.

The treadmill protocol is designed to measure the changes in step count accuracy that occurs with changes in pedometer tilt angle. A second set of treadmill walking trials will test the second pedometer mechanism which was not worn during the first set of trials.

Each participant is presented with this *Informed Consent Document* which explains the purpose of the testing, as well as expected risks and benefits associated with participation. It is the participant's responsibility to acquire medical clearance from his/her physician prior to lab testing.

Each participant will also be screened by the project director using responses provided by participants in the **Physical Activity Readiness Questionnaire (PAR-Q)** (the PAR-Q is attached to the end of this document). This procedure is in compliance with policies formulated by the American College of Sports Medicine¹.

Please talk with the Project Director, Melissa Dock, about any pre-existing health conditions that may limit your participation in this project *BEFORE* testing.

STUDY PROCEDURES:

You (the participant) will be required to make two visits to the Movement Science / Human Performance Lab (basement of Romney Building) within a one month period. The first visit will last approximately one and a half hours. You should arrive at the lab ready to engage in light intensity walking. Therefore, you should dress in running/walking shoes, fitted pants with belt loops, and a fitted shirt. You should also eat, and drink fluids appropriately for the occasion. *If you use an inhaler to treat asthma, make certain to bring the inhaler with you to the lab.* The second visit will last approximately one hour. You should be prepared for light intensity walking and dress appropriately (running/walking shoes, fitted pants with belt loops, a fitted shirt).

Session #1 - Test Protocol.

Treadmill Walking: You will wear a belt with two pedometers: one attached to a pedometer gimbal at an altered tilt angle and one worn in a neutral position (0 degrees). You will walk 21 total trials, lasting one and a half minutes, at a combination of treadmill speeds (67.0, 80.4, 93.8 m/min, or 2.5, 3.0, 3.5 mph) and one of six pedometer tilt angles (-30, -20, -10, 0, +10, +20, +30 degrees). Tilt angle is the positive or negative degree to which the pedometer deviates from zero. There will be a 30 second rest interval in between trials for recording steps and adjusting the treadmill speed and pedometer tilt angle.

Session #2- Test Protocol:

The treadmill walking trials will be exactly the same on the second visit, but with a different pedometer mechanism.

POTENTIAL RISKS:

The treadmill testing carries minimal risks. The exercise intensity is light and you (the participant) are in good physical condition. *These risks are no more than those experienced by individuals during normal daily activities.*

BENEFITS:

You will receive a Digiwalker SW 200 pedometer (\$20 value) and receive feedback on the accuracy of pedometers. Additionally, study participants may request a summary of the study findings by contacting the Project Director, Melissa Dock, by phone (406-595-7915) or by e-mail (melissa.dock@myportal.montana.edu).

CONFIDENTIALITY:

The data and personal information obtained from this study will be regarded as privileged and confidential. Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. Your

¹American College of Sports Medicine (2006). *ACSM's Guidelines for Exercise Testing and Prescription* (7th edition). Lea & Fibiger; Philadelphia, PA.

right to privacy will be maintained in any ensuing analysis and/or presentation of the data by using coded identifications of each person's data. The code list will be kept separate and secure from the actual data files.

FREEDOM OF CONSENT:

Participation in this project is completely voluntary. You may withdraw consent for participation in writing, by telephone, or in person without prejudice or loss of benefits (as described above). Please contact the Project Director, Melissa Dock, by phone (406-595-7915) or by e-mail (melissa.dock@myportal.montana.edu) to discontinue participation.

In the UNLIKELY event that your participation in the project results in physical injury to you, the Project Director will advise and assist you in receiving medical treatment. No compensation is available from Montana State University for injury, accidents, or expenses that may occur as a result of your participation in this project. Additionally, no compensation is available from Montana State University for injury, accidents, or expenses that may occur as a result of traveling to and from your appointments at the Movement Science / Human Performance Laboratory. *Further information regarding medical treatment may be obtained by calling the Project Director, Melissa Dock, at 406-595-7915.* You are encouraged to express any questions, doubts or concerns regarding this project. The Project Director will attempt to answer all questions to the best of their ability prior to any testing. The Project Director fully intends to conduct the study with your best interest, safety and comfort in mind. *Additional questions about the rights of human subjects can be answered by the Chairman of the Human Subjects Committee, Mark Quinn, at 406-994-5721*

<p>PROJECT TITLE: <i>Influence of Pedometer Tilt Angle on Step Counting Validity during Controlled Treadmill Walking Trials</i></p>
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STATEMENT OF AUTHORIZATION

I, *the participant*, have read the Informed Consent Document and understand the discomforts, inconvenience, risks, and benefits of this project. I, _____
(print your name), agree to participate in the project described in the preceding pages. I understand that I may later refuse to participate, and that I may withdraw from the study at any time. I have received a copy of this consent form for my own records.

Signed: _____ **Age** _____ **Date** _____
Subject's Signature

Witness: _____ **Date** _____
Print Name *Sign Name*

APPENDIX B

PAR-Q: PHYSICAL ACTIVITY READINESS QUESTIONNAIRE

PAR-Q: PHYSICAL ACTIVITY READINESS QUESTIONNAIRE

PAR-Q is designed to help you help yourself. Many health benefits are associated with regular exercise and completion of a PAR-Q is a sensible first step to take if you are planning to increase the amount of physical activity in your life. For most people, physical activity should not pose any problem or hazard. PAR-Q has been designed to identify the small number of adults for whom physical activity might be inappropriate or those who should have medical advice concerning the type of activity most suitable for them.

Common sense is your best guide in answering these few questions. Please read the following questions carefully and check the **YES** or **NO** opposite the question if it applies to you.

YES **NO**

- | | | |
|--------------------------|--------------------------|--|
| <input type="checkbox"/> | <input type="checkbox"/> | 1. Has your doctor ever said you have heart trouble? |
| <input type="checkbox"/> | <input type="checkbox"/> | 2. Do you ever have pains in your heart or chest? |
| <input type="checkbox"/> | <input type="checkbox"/> | 3. Do you ever feel faint or have spells of severe dizziness? |
| <input type="checkbox"/> | <input type="checkbox"/> | 4. Has a doctor ever said your blood pressure was too high? |
| <input type="checkbox"/> | <input type="checkbox"/> | 5. Has a doctor ever said your blood cholesterol was too high? |
| <input type="checkbox"/> | <input type="checkbox"/> | 6. Have you ever been diagnosed with diabetes mellitus? |
| <input type="checkbox"/> | <input type="checkbox"/> | 7. Has your doctor ever told you that you have a bone or joint problem such as arthritis that has been aggravated by exercise, or might be made worse with exercise? |
| <input type="checkbox"/> | <input type="checkbox"/> | 8. Is there a good physical reason not mentioned here why you should not follow an activity program even if you wanted to? |
| <input type="checkbox"/> | <input type="checkbox"/> | 9. Are you over the age of 65 or NOT accustomed to vigorous exercise? |
| <input type="checkbox"/> | <input type="checkbox"/> | 10. Are you a habitual cigarette or cigar smoker? |

If "Yes", how many years? _____

If "No" AND you have recently quit smoking, how long ago did you quit?
_____ (give answer in months or years)

- | | | |
|--------------------------|--------------------------|---|
| <input type="checkbox"/> | <input type="checkbox"/> | 11. Is there any other physical ailment not mentioned above that could be considered a health risk if you were to participate in the testing described by the Informed Consent Document? If "Yes", please describe below... |
|--------------------------|--------------------------|---|

If you answered "YES" to one or more questions...

If you have not recently done so, consult with your personal physician by telephone or in person before increasing your physical activity, taking a fitness test, or participating in the present research study. Tell the physician what questions you answered "YES" on PAR-Q or show a copy of this form. Be certain to talk with the principal investigator before proceeding further with your involvement in this study.

If you answered "NO" to all questions...

You have reasonable assurance that your participation in the present study will not put you at higher risk for injury for illness.

NOTE: Postpone exercise testing if you suffer from minor illness such as a common cold or flu!

Your signature below indicates that you have filled out the preceding PAR-Q form to the best of your knowledge.

Signed: _____ Date _____
Subject's Signature

Signed: _____ Date _____
Project Technician