AN ABSTRACT OF THE THESIS OF

Caitlyn A. Elliott for the degree of Master of Science in Exercise and Sport Science presented on June 10, 2013
Title: Assessing the Accuracy of Common Methods used in Measuring Physical Activity with Pedometers

Abstract Approved:

_______________________________________________________________
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Monitoring physical activity has been a dominant topic of research for many years. Being physically active has been shown to decrease health related issues, including obesity, cardiovascular disease, and even premature death. Multiple researchers have studied monitoring physical activity, but the actual method of measuring physical activity in a free-living condition has not gotten much attention. The purpose of this study was to examine the accuracy of pedometers when employing the common instructions of pedometer wearing time. This study focused on three questions: a. What percent of time would participants wear pedometers following the popular method of wearing pedometers during participant’s awake time? b. Were missing data affected by certain individual characteristics? c. What were the effects on compliance when using a physical activity log? Method: The study at hand was a blind study; the participants were not privy to the specific research questions, to avoid potential reactivity. 17 individuals (6 males, 11 females) from the Pacific
Northwest were recruited and then randomly selected into either the experimental or the control group. Participants were equipped with one Actical® accelerometer on their wrist. They were also given a belt with one Actical® accelerometer and one Omron 720-ITC pedometer. The experimental group received a pedometer log to measure wear time; the control group did not. Participants wore these devices for seven days to monitor physical activity and missed wearing time. Missed wearing time was determined by comparing counts on both accelerometers. Results: Participants missed a mean amount of 111.76 minutes per day. Participants wore their pedometers for a mean of 14.26 hours per day. BMI, gender, group, and levels of physical activity were examined for potential effects on missing data. A multiple regression indicated a significant negative relationship between level of physical activity and missing data, ($\beta = -0.61$, $p < 0.01$). Although Pedometer logs have the potential to decrease missed physical activity measurement by a pedometer, a one-way ANOVA showed there were no statistical differences between the control and experimental group, $F(1,15) = 0.186$ $p > 0.05$. People who are more physically active have the potential to be more compliant about wearing his or her pedometer.
Assessing the Accuracy of Common Methods used in Measuring Physical Activity with Pedometers

by
Caitlyn A. Elliott

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CONTRIBUTION OF AUTHORS

Dr. Yun contributed to the data collection and analysis of the data in this study.
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Chapter 1: Introduction

There has been an increased interest in the use of objectively measuring physical activity over the last 10 years. In the past, self-report methods have been commonly employed to determine physical activity levels for individuals; however, the need to accurately and objectively measure physical activity has increased (Tudor-Locke & Myers, 2001). Of the many forms of physical activity, walking is considered the most common form of leisure time physical activity. Walking also serves as a means of transportation and social interaction (Schneider, Crouter & Bassett, 2004; Tudor-Locke & Myers, 2001; Stanish & Draheim, 2005). Because of this, walking has been a popular and logical way to measure physical activity levels in the general population.

The most commonly used tool for objectively measuring walking is the pedometer (Stanish & Draheim, 2005). Pedometers are practical for use in field studies and when the outcome measure is steps per day (Tudor-Locke, Basset, Shipe, & McClain, 2011). Pedometers can also be advantageous in identifying dose-response relationships in intervention studies, such as when the researcher is determining if a specific amount of steps has an effect on health (Schmidt, et al., 2007). Assessing physical activity through the use of a pedometer can be especially helpful, due to the popularity of walking for exercise.
Pedometers have been thoroughly researched and evaluated for accuracy and reliability (Tudor-Locke & Meyers, 2001). There are two popular types of pedometers used to measure the steps taken by an individual. Steps are measured by either a lever arm mechanism, or an accelerometer, known as the piezoelectric crystal technology (Schneider, Crouter & Bassett, 2004). Of those two, the most popular type of pedometer used today is the piezoelectric pedometer. Piezoelectric pedometers have shown to maintain reliability with increased pedometer tilt when worn on a waistband (Crouter, Schneider & Bassett, 2005; Clemes, O’Connell, Morgan & Griffiths, 2009). This can be advantageous when monitoring people with increased body mass index or individuals with body shapes considered, “apple shaped.” In addition, these pedometers can be worn in multiple different locations. The recommended location of a pedometer is dependent on the kind of pedometer being used.

There is common methodology used in the majority of studies focuses on determining physical activity levels of individuals, however, there is no clear consensus on measurement protocol specifically related to pedometer wearing time (Tudor-Locke, Bassett, Shipe, & McClain, 2011). The most commonly employed methodology includes wearing a pedometer for three to seven consecutive days (e.g. Tudor-Locke & Myer, 2011; Tudor-Lock Bassett, Shipe & McClain, 2011). In these studies, a day consists of the total time a subject wakes up in the morning to the time a subject goes to bed, excluding showering and swimming. This method of measurement includes a few
important assumptions. First, this assumes the subjects generally follow the
instruction on wearing time (wear the pedometers when they wake up).
Second, it assumes missing data from subjects is random. In other words, this
assumes issues associated with non-compliance are not related to a certain
group or population and/or any systematic variables. Without meeting these
assumptions, the ability to compare physical activity levels between different
studies and populations becomes problematic. For example, assume a
researcher intends to compare the number of steps taken between an older and
a younger population. If the younger population systematically forgets to wear
pedometers and the older population does not, the number of steps measured
by pedometer is difficult to compare between older and younger populations.

Despite these concerns, prominent researchers have argued that
wearing times of pedometers may not be a major issue. Tudor-Lock et al.
(2011) stated there is no standardized amount of hours a pedometer must be
worn in one day to constitute a valid day. However, Tudor-Locke et al. (2011)
states three “days” of pedometer data is enough to predict habitual or long-
term physical activity. In addition, Schneider at al. (2003) reported that after 14
hours of wear time in one day, the correlation of habitual physical activity was
sufficient and did not improve with more hours of wear time. Previous studies
suggested the amount of time a pedometer is worn does not alter the magnitude
of the relationship between physical activity and the relevant health related
issues (Schmidt et al., 2007; Tutor-Locke, Bassett, Shipe & McClain, 2011).
Therefore, the researchers concluded the error associated with time worn is random and might not be a serious issue.

In terms of a public health perspective, the previous researchers’ point of view on the amount of wearing time could be a reasonable conclusion considering the extent of association between two variables is not affected by pedometer wearing time. However, this can be a noteworthy problem if researchers or practitioners intend to use the absolute amount of steps as the dependent variables for research projects such as comparing the effectiveness of intervention strategies, or the number of steps as the objective of a health promotion program. Without meeting the assumptions made by common methodology, and not knowing how much information is actually missed by inconsistent pedometer wearing time, it would be practically impossible to directly compare the absolute amount of physical activity between multiple studies. It would also be impossible to examine the effectiveness of an intervention program without consistent data collection across multiple studies. Thus, the purpose of this study was to examine the accuracy of pedometers when employing the common instructions of pedometer wearing time.

The following specific research questions were asked to examine the purpose of the current study:
Research question 1: What percent of time will participants wear pedometers when following the popular method of wearing pedometers during participant’s awake time?
Research question 2: Is missing data affected by certain characteristics of individuals (e.g. age, level of physical activity, gender, etc.) associated with the pattern of missing data?

Research question 3: What are the effects on compliance when using a physical activity log?

Assumptions

The following assumptions were made:

1. There is a limited amount of reactivity with pedometer use
2. Cut-off scores to identify sleep pattern accurately identifies awake time and sleep time

Delimitations

1. Measuring physical activity levels of individuals was limited to individuals only in the Pacific Northwest.
2. Omron HJ 720 ITC was the pedometer selected for the study
3. The study lasted seven days

Limitations

1. Intermittent walking might not have been recognized due to a four second recording delay programmed into the selected pedometer.
Chapter 2: Literature review

An increase in physical activity has shown to be beneficial and contributory towards a healthy lifestyle. Pedometers have often been used as physical activity measurement tools due to their objectivity and ease of use. Pedometers have been researched and assessed time and time again; however, the current measurement methods could create an issue when comparing absolute levels of physical activity because of a limitation associated with the current approach. The purpose of this thesis is to investigate the amount of missing information and the pattern of this missing information created by the current method. This literature review provided background information about physical activity and pedometer measurements. It is composed of the following topics (a) physical activity, (b) benefits of physical activity, (c) popular forms of physical activity, (d) pedometers, and (f) the popular pedometer protocols that have been previously employed in studies.

Physical Activity

Physical activity, exercise, and physical fitness are terms commonly interchanged in the general population. There are, however, distinct definitions and uses for each specific term. Each term builds on the next, which ultimately encompasses physical activity. Physical activity is defined as “any bodily movement produced by skeletal muscles that results in energy expenditure” (Casperson, Powell, & Christension, 1095, p. 126). This
definition has been utilized and endorsed by the American Heart Association as well as the American College of Sports Medicine (Thompson, Buchner, Piña et al., 2003). Exercise is a subset of physical activity. Exercise is defined as “planned, structured, and repetitive bodily movement done to improve or maintain one or more components of physical fitness” (Caspersen et al., 1985, p. 128). Physical fitness is the objective of exercise and is described as, “a set of attributes that people have or achieve that relates to the ability to perform physical activity” (Caspersen et al., 1985, p. 128). Physical fitness has also been described as “a physiologic state of well-being that allows one to meet the demands of daily living or that provides the basis for sport performance (Warburton, Nicol, & Bredin, 2006, p. 804). Physical activity and exercise are positively correlated with physical fitness,” (Caspersen, Powell, & Christenson, 1985). Both level of physical activity and physical fitness are used as indicators of risk of morbidity.

Benefits of Physical Activity

Having a physically active lifestyle can contribute to a decrease in chronic diseases such as cancer, diabetes mellitus, cardiovascular disease, depression, osteoporosis, hypertension, obesity, and ultimately premature death (Pate et al., 1995; Warburton, Nicol, & Bredin, 2006). A multitude of research has reported the health benefits of being physically active (e.g. Tudor-Locke, Burton, & Brown, 2009; Dranheim, Williams & McCubbin, 2002;
Warburton, Nicol, & Bredin, 2006). For example, Myers et al. (2004) reported a 50% reduction in the risk of death and cardiovascular disease among inactive adults. Another study by Tuomilehto et al., (2001) reported that with simple lifestyle changes the incidence of diabetes mellitus dropped 58%. These changes included education of the benefits of physical activity and information about moderate activity. Even a small increase in physical activity has been shown to significantly decrease the predictive diagnosis of coronary heart disease as well as premature mortality (Eriksson et al., 1998). Weight bearing activities have shown to have the greatest effect on bone density. Walking is a weight bearing activity, thus it has been shown to increase bone mineral density (Warbuton, Nicol, & Bredin, 2006), as well as the innumerable health benefits previously discussed.

An increase in physical activity has been shown to have a strong effect in decreasing body mass index (BMI). Tudor-Locke et al. (2001) examined the relationship between the steps measured by a pedometer and body composition. Tudor-Locke et al. (2011) concluded the majority of the participants with the highest level of activity, measured as the most steps per day, were classified as normal weight. Higher body mass indexes and body compositions were linked to lower levels of physical activity measured by a pedometer.

Apart from physical benefits, there are also many psychological benefits that are associated with an increase in physical activity. In the past,
mental health has been a major contributor to health care costs in America (Taylor, Sallis, & Needle, 1985). Increasing physical activity has been linked to decreases of negative behavior such as depression, anger, stress responses and certain psychotic behaviors (e.g. Taylor, Sallis & Needle, 1984; Wankle, Alberat & Berger, 1990). Physical activity has also been linked to decreasing mild to moderate depression (Haskell, Montoye, Orenstein, 1985; Taylor, Sallis, & Needle, 1985). People suffering from depression and were treated with prescribed physical activity showed lower scores on the Profile of Mood State scale (Taylor, Sallis & Needle, 1984). Involvement in physical activity can promote a short-term decrease in state anxiety as well as tension (Taylor, Sallis, & Needle, 1984). In a study that assessing anxiety levels following a jogging program, results showed self-efficacy increased with continuous participation in physical activity (Wankel, Alberat, & Berger, 1990). Physical activity has also been successfully linked to an increase in certain positive behavior such as mood, positive body image, emotional stability and memory (Taylor, Sallis & Needle, 1985; Wankel, Alberat & Berger, 1990). Prescribing physical activity has been suggested to be beneficial in the management of mental disorders. Participation has also shown to modestly increase quality of life in an individual (Taylor, Sallis, & Needle, 1985). This trait can help with integration into a social atmosphere more smoothly (Wankel, Alberat & Berger, 1990). Mental wellbeing continues to be an extremely important aspect of a healthy lifestyle in individuals.
Popular Forms of Physical Activity

There are many forms of leisure-time physical activity, however, walking is the most common and fundamental form, followed by water-based activities (Finlayson, Jackson, Cooper, Morrison, Melville, Smiley, Allen, Mantry, 2009) Walking is a form of exercise, as well as a means for transportation and other recreational and social activities. There are many sources reporting walking as one of the most popular forms of physical activity (e.g. Schneider, Crouter & Bassett, 2004; Tudor-Locke & Myers, 2001; Stanish & Draheim, 2005; Weiker, Dlugonshki, Balantrapu, & Motl, 2011). Specifically, one particular study (Finlayson, et al., 2009) sought out to determine why physical activity levels are low and what the most common forms of physical activity in order to determine how to encourage individuals to participate more regularly. Walking can be a form of exercise, transportation and sport. In the United States, there are many public campaigns emphasizing physical activity to the general public. These campaigns include 10,000 Steps a Day, America on the Move, and Steps to a Healthier US. These are all initiatives that encourage an increase in physical activity through walking. These initiatives employ the use of a pedometer to encourage participants to set walking goals (Stanish & Draheim, 2005). The United Kingdom recently initiated a campaign called the Step-O-Meter Programme. This program’s main motivational tool was a pedometer to help with goal setting (Clemes,
Pedometers

Pedometers have been recognized as a practical and objective tool for measuring physical activity (Stanish & Dranheim, 2005). These devices are practical, inexpensive, and easy to use. (Tudor-Locke et al., 2001; Tudor-Locke, Williams, Reis, & Pluto, 2002) They have become increasingly popular due to a plethora of everyday applications. A pedometer is a motion sensor that produces objective measurement output. This practical objective tool is useful for researchers, as well as the general population. Pedometers are easy to use as a goal setting tool for individuals wishing to increase physical activity levels. The raw data output from a pedometer is quick and easy to interpret, while raw data from an accelerometer is essentially unable to interpret without additional training and computer software.

There are two popular kinds of pedometers commonly used today—a spring lever/pendulum pedometer and a piezoelectric pedometer. Spring lever pedometers use inertia from the vertical hip movement to close the circuit, which in turn becomes a step (Schneider, Crouter, & Bassett, 2004). Piezoelectric pedometers employ a different measuring component inside. Piezoelectric pedometers use the same mechanism as an accelerometer, but it converts body motion to the number of steps rather than a physical activity count. This particular kind of pedometer has no moving parts and uses an
electric mechanism to measure vertical movements that register as steps (Schneider, Crouter & Bassett, 2004). These pedometers are better at detecting slower movements, and can generally be worn anywhere, thus angle of attachment is not as important as it is for a spring-lever pedometer (Crouter, Schneider & Bassett, 2005).

Although a pedometer is a practical and useful for measuring physical activity, there are some issues with specific types of them. Spring lever pedometers are more accurate when they are placed perpendicular to the ground. This kind of pedometer can be greatly affected by the angle at which the pedometer is fixed. This causes issues for some people, especially those who are overweight. A recent study examining the accuracy of the Silva spring pendulum pedometer, reported that accuracy of the pedometer decreased some with an increase in body mass index. (Clemes, O’Connel, Morgan & Griffiths, 2009). Pedometer accuracy has been reported to decrease with an increase in waist circumference (Crouter, Schneider, & Bassett, 2005).

Alterting the position of the pedometer will greatly affect the amount of steps registered. Generally, spring lever pedometers tilted to greater than 60 degrees have significant flaw (Clemes, O’Connel, Morgan & Griffiths, 2009). Tilting can be due to placement on the body as well as subjects body composition. For individuals who carry excess weight around the midsection of their body, a spring level pedometer would not be ideal. A recent study by Crouter, Schneider and Bassett (2005) focused on investigating the accuracy of
piezoelectric and spring-levered of overweight and obese adults. The study was specifically interested in determining if pedometer tilt due to waist circumference affected the accuracy of pedometers. The authors reported the piezoelectric pedometer (New-Lifestyles NL-2000) maintained acceptable accuracy with a pedometer tilt of up to 15 degrees. The spring lever pedometer tested, the (Digi-Walker SW0200), however, became less accurate with increases in body mass index causing pedometer tilt (Crouter, Schneider, & Bassett, 2005).

A piezoelectric pedometer is extremely beneficial when measuring individuals who have an accumulation of adipose tissue predominately in the abdomen. In a recent study of individuals with Down syndrome by Pitchford and Yun (2009), it was determined that spring lever pedometers have a significant decrease in measurement accuracy than piezoelectric pedometer. The authors suggested a decrease in accuracy could be related to increases on pedometer tilt due to abdominal adipose tissue accumulation; common in people with Down syndrome. Slower walking speeds also have a great effect on accuracy of pedometers (Pitchford, & Yun, 2009).

Pedometers have long been tested for accuracy against the more sophisticated tool such as accelerometers (Tudor-Locke & Myers, 2001). In a study by Bassett, et al., (2000) pedometer accuracy was compared against the accuracy of accelerometers. Pedometers showed a high level of agreement with accelerometers ($r = 0.8-0.9$) (Bassett, et al., 2000). Also, pedometers can
consistently count steps in order to be compared to step counts when synthesizing studies. A recent study compared the accuracy of 13 different pedometers using the Yamax Digi-Walker YX200 as the criterion measure (Schneider, Crouter, & Bassett, 2004). There were two pedometers the authors determined to be within 10% of the criterion measure. These two pedometers were the Colorado on the Move, and Sport Line 345. Accurate pedometers are necessary for standardization because significant error can results in different activity classification (Schneider, Crouter, & Bassett, 2004).

Spring-lever pedometers also have issues accurately measuring steps when walking speeds are less than 60 meters per minute (Tudor-Locke, Ainsworth, Thompson & Matthews, 2002). Piezoelectric pedometers are more accurate when measuring walking at slower speeds. Piezoelectric pedometers are accurate for walking speeds as slow as three miles per hour (Tudor-Locke, Ainsworth, Thompson & Matthews, 2002). Data can be stored in the pedometer for up to 41 days. The Omron-720 ITC contains two accelerometers 90 degrees from each other; ensuring pedometer tilt will not affect measurement (Bassett & John, 2010). Bassett and John (2010) reported following a one-mile trial walk, and absolute percent error was less than 3%. Further tests were done to determine accuracy during self paced trials, and the coefficient of variance was less than 2.1%. In a 24 hour free-living condition trial, the Omron-720 ITC was worn on three groups; a normal weight, over-weight, and obese group. Results of the study showed the Omron 720 ITC
was the most accurate in the obese group, counting 65% of the participant’s
steps (Silcot, Bassett, Thompson, FitzHugh, & Steves, 2011).

Popular Pedometer Methodology

The use of the pedometer to measure physical activity has remained
popular for many years. The methodology has been described using multiple
variations, however the basis remains the same. The methodology that is most
commonly used includes the participant being instructed to wear the pedometer
during all waking hours excluding water-based activities and showering
(Tudor-Locke et al., 2001). With the use of this type of measurement
methodology, pedometers have shown to be worn between 13.4 and 14.9 hours
a day on average (Leenders, Sherman & Nagaraja, 2000; Thuy, Blizzard,
Schmidt, Magnussen, Hansen, & Dwyer, 2011). Multiple studies have been
done to determine habitual physical activity levels of individuals. Rarely, do
the studies specify the amount of time needed to determine these physical
activity levels. One particular study looked at long-term physical activity levels
for students in the Czech Republic. Participants were given a pedometer to
wear every day for one year. They were also given a journal to record their
daily activity and step counts. The authors noted that for a day in this study to
be valid, they must wear the pedometer at least 10 hours a day, however, there
was no justification as to why 10 hours was considered a full day (Pelcolva,
Walid, & Vasickova, 2010). A study by Rooney, Smalley, Larson, and Havens
(2003), noted that when participants measuring their own physical activity incorporated the use of a physical activity log, were more likely to set aggressive step goals and were also more likely to wear the pedometer for more hours per day. This study also concluded that with the addition of physical activity logs, participants had higher levels of self-efficacy following the study (Rooney, Smalley, Larson, & Havens, 2003).

Another study measuring physical activity in individuals with intellectual disabilities used pedometers for seven days (Stanish, 2004). They used the common method of instructing the participant to put the pedometer on when they got up, and take it off when they went to bed—excluding water based activities and showering. The author deemed seven days as adequate measurement time with reference to Tudor-Locke and Myers (2001) study regarding adequate measurement to determine long-term physical activity (Stanish, 2004). Duration of pedometer measured physical activity has been widely researched. Thuy et al. (2011) determined prediction of long-term physical activity could be accomplished with only four days of measurement; with little change in the correlation as the days increased. They later went on to discuss that after three days of measurement the output became steady. Thuy et al (2011) discussed the issue of reactivity and suggested five days of total wear time, with only three days of measurement; leaving the first two days to account for reactivity of the device. Reactivity could be responsible for 10-15% of an increase in output data, specifically if the step counts are visible.
Tudor-Locke & Myers (2011) recommend keeping the pedometer sealed when possible to decrease the amount of reactivity. Tudor-Locke and Myers (2011) agree with Thuy, and discussed that three days of measurement is capable of producing sufficient reliability. Tudor-Locke and Myers (2011) determined that with three days of measurement data, the interclass correlation is between 0.80 and 0.90; an acceptable ICC is above 0.70 (Tudor-Locke & Myers, 2011). The length of measurement is determined by what the researcher is studying and the desired reliability criterion (Tudor-Lock et al., 2011). In individuals with more stable daily patterns or daily variability, fewer days may be necessary to achieve proper reliability (Tudor-Locke, & Myers 2011).

**Accelerometers**

An accelerometer is another tool that is used to monitor physical activity in individuals with and without disabilities. Like the pedometer, the accelerometer measures physical activity objectively (Ward, et al., 2005). The accelerometer is compact, portable, and does not have a display. All the previous characteristics are beneficial for measuring physical activity in a free-living environment (Ward, et al., 2005; Chen & Bassett, 2005). The mechanism that accelerometers employ, however, is different than a pedometer. The output given by an accelerometer is also much different than a pedometer. Unlike the pedometer, the output data of an accelerometer is not as easily read by a layperson. Accelerometers provide activity counts based on an
algorithm developed by a specific manufacturer. Though, most researchers
convert physical activity counts to the amount of energy expenditure of daily
activities using various equations derived from different cut-points. However,
a recent report by Bassett, Rowlands and Trost (2012) directly challenged the
validity of activity counts to predict energy expenditure.

**Measuring Sleep**

There are multiple ways to measure sleep including the
polysomnography (PGS), sleep questionnaires, and accelerometers (Jean-
Louise & Gizycki 1997; Girschik, Fritschi, Heyworth & Waters, 2012). Because the accelerometer is small, portable, objective, and easy to use, accelerometry has become a popular method to assess sleep patterns in field studies. When sleep patterns were studied examining the accuracy of PGS versus accelerometry, there was a strong correlation coefficient between the two (r = 0.93). Sleep shown by actigraphy resulted in a strong correlation coefficient for sleep time as well, (r = 0.97, p<0.01) with a mean discrepancy of about 12 minutes between the two tools (Jean-Louise & Gizycki, 1997). Girschik, Fritschi, Heyworth and Waters (2012) also studied the relationship between sleep questionnaires and actigraphy. Though, questionnaires have been viewed as the most practical way to measure sleep in large samples or epidemiological studies, the authors challenged the accuracy of using questionnaires versus using objective measurement such as accelerometry.
When accelerometry was tested against sleep questionnaires, there was little agreement between the two. Sleep duration was considerably underestimated when using a self-report method (Girschik, Fritschi, Heyworth & Waters, 2012). Ancoli-Israel, et al (2003) agreed that though accelerometry is not as accurate at PGS when measuring sleep, it is better than various self-report methods such as sleep logs or questionnaires. Accelerometry was also suggested to be more practical than PGS for certain populations such as young children or babies and elder patients with dementia (Ancoli-Israel, et al, 2003).

When accelerometry was tested against sleep questionnaires, there was little agreement between the two. Sleep duration was considerably underestimated when using a self-report method (Girschik, Fritschi, Heyworth & Waters, 2012).

In a previous study by Garnier and Benefice (2006), sleep was measured with the use of cut-off points (Garnier & Benefice, 2006) to identify the sleeping patterns. The authors focused on measuring sleeping patterns and physical inactivity of adolescents in regards to public health issues, participant’s time awake was determined by subtracting sleep measurement. Sleeping was characterized by accelerometer counts less than 25 for more than five consecutive minute epochs between the hours of 8:00 and 12:00pm. Participants were considered to be awake after 12:00 and when there was an abrupt change in activity for at least five consecutive minutes with counts above 100 (Garnier & Benefice, 2006).
Chapter 3: Methods

Participants

The study consisted of a convenience sample of 17 participants (6 males, 11 females). The participants were between the ages of 21 and 37 years old, with the mean age of 25.22. The participants were recruited from a university campus in the Northwest and the surrounding Northwest community. As part of the eligibility criteria, participants had a balanced gait, and did not use any assistive devices. Participants were screened for participation by using a questionnaire asking if they had had any previous severe injuries to their lower extremities (Appendix B). The questionnaire also inquired about general health issues that could potentially limit a participant’s ability to walk. The participants were divided into an experimental and control group. The control group consisted of eight participants (8 females, 1 male). The experimental group consisted of nine participants (4 females, 5 male). Table 1 shows the demographic characteristics of each participant.
Table 3.1 Participant Demographic Data

<table>
<thead>
<tr>
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<td>84.94</td>
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<td>171.5</td>
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Research Design

This study employed a blind randomized experimental design because directly informing the specific research questions could potentially alter the participants’ behavior. The participants were informed of the overall purpose of study (examining the accuracy of pedometer as measuring physical activity), but the specific research questions: (a) how much information is missing due to a lack of compliance, (b) what are the potential characteristics that may influence a pattern of missing data, and (c) evaluating the effects of physical activity log, was not discussed prior to data collection. After data collection was completed, the participants were clearly informed of each specific research
question. The participants were given an option to withdraw their data from the study if they wished. Oregon State University Intuitional Review Board approved the study procedure.

**Instruments**

*Pedometer.* The pedometer used in this study was the Omron-720 ITC pedometer (Omron Healthcare, Bannockburn, Illinois). This pedometer is equipped with a piezoelectric mechanism. It has the ability to breakdown activity by the hour; this allowed the researcher to compare activity by the hour with the data collected from an accelerometer. Data can be stored in the pedometer for up to 41 days. The Omron-720 ITC contains two accelerometers 90 degrees from each other; ensuring pedometer tilt will not affect measurement (Bassett & John, 2010). Bassett and John (2010) reported following a one-mile trial walk, and absolute percent error was less than 3%. Further tests were done to determine accuracy during self paced trials, and the coefficient of variance was less than 2.1%. In a 24 hour free-living condition trial, the Omron-720 ITC was worn on three groups; a normal weight, over-weight, and obese group. Results of the study showed the Omron 720 ITC was the most accurate in the obese group, counting 65% of the participant’s steps (Silcot, Bassett, Thompson, Fitzhugh, & Steves, 2011).

*Accelerometer.* Actical accelerometers (Mini-Mitter, Bend, OR) were used to assess the sleeping pattern of the participants as well as monitor wear
time. Actical has an omnidirectional sensor which monitors acceleration of body movement in all directions (Puyau, Adolph, Vohra, Vohra, Zakeri, & Butte, 2004). Data can be stored for up to 44 days (Bassett & John, 2010).

**Testing Procedures**

Each participant was asked to wear two accelerometers and one pedometer to monitor activity for one week. One accelerometer was threaded onto a hospital style bracelet, so the participant could not remove the monitor during data collection. The purpose of the accelerometer on the wrist was to measure awake time and to measure the amount of time that data collection was missed by the pedometer. The second accelerometer and the pedometer were attached to an elastic belt. Wear time of the pedometer was calculated by comparing the accelerometer on the wrist to the accelerometer on the belt. The accelerometer on the belt was used to accurately measure wear time of the pedometer. Prior to each meeting, the researcher calibrated all of the instruments per each participant to the same time.

In the initial meeting, the researcher gathered demographic data, including age, weight, and height. A researcher measured height and weight. After the demographic information was collected the participants were randomly separated into the experimental or control group. Participants selected to be in the experimental group were given an exercise log and instructed how to record activity in the log (Appendix C). All Participants were given their monitors (one belt, one bracelet). The bracelet was clipped in
place at this time. This bracelet was not removable, unless the participants intentionally cut-off the bracelet. Participants were shown where to place the belt on his or her hips. Participants were instructed to wear the belt in a position where the accelerometer and pedometer were placed on his or her right hip, medial to the anterior superior iliac crest, and perpendicular to the ground. All participants were instructed to put the belt on when they first woke up, and take the belt off when they went to bed, excluding showering and water-based activities. Finally participants were asked to not alter their normal daily physical activity behavior.

Approximately 8 days after the initial meeting, the participants met one on one with the researcher for a debriefing session. The meeting consisted of the researcher explaining the specific questions of the study. The bracelet with the accelerometer was cut off, and the waist belt with the accelerometer and the pedometer was returned. The experimental group also returned their pedometer log. At that time, participants were given the option to deny permission to use their data. No participants denied the use of their data.

Analysis

*Data Reduction.* To reduce the data, the researcher compiled all the pedometer and accelerometer data. Awake time was determined using the data collected by the accelerometer worn on the participants’ wrist. Based on a previous study, awake time was determined by the number of activity counts at a given time (Garnier & Benefice, 2006). Participants were considered
sleeping when accelerometer were less than 25 counts per minute for more than five consecutive minute epochs between the hours of 8:00pm and 12:00pm. Participants were considered to be awake anytime after 8:00pm when there was an abrupt change in activity for at least five consecutive minutes with counts above 100 (Garnier & Benefice, 2006). Wear time of the belt was determined by an abrupt change in the accelerometer worn on the hip. The awake time data from the accelerometer worn on the wrist was compared to the wear time data from the accelerometer worn on the hip. For our study, one day was considered to be the time period from when the participant woke up to the time the participant went to sleep.

After the initial reduction, data was further reduced into average missing minutes per week, and day; and was then further separated into average missing minutes during the weekdays and the weekend. Pedometer data was further reduced into total steps, average steps, average steps per day on the weekdays, and average steps per day on the weekend days. Hours worn was calculated per day, and was reduced into average hours worn per day, weekday and weekend. Hours worn was calculated by counting the hours the waist belt was worn. This was reduced into average hours worn per day, weekday, and weekend day. This information was used to answer each research question as follows.
The following statistics procedures were employed to answer each of the research questions:

Research Question 1: What percent of time will participants wear pedometers when following the popular method of wearing pedometers during participant’s awake time?

The dependent variable of this question is the percentage of time pedometers are worn in a day. Analysis was done using a simple calculation dividing the number of minutes spent awake by the amount of minutes the participant wore his or her waist-belt. Values were presented in percentages. A one way-ANOVA was also run to compare between control and experimental groups.

Research question 2: Are certain characteristics of the participants associated with a pattern of missing data?

The independent variables are BMI, age, gender and height data. The dependent variable used was the average minutes of missing data. Analysis was done using a linear multiple regression using a b-coefficient to determine if there are differences between the other demographic variables.

Research question 3: What are the effects of incorporating a physical activity log?
The amount of missing time in minutes was used as the dependent variable and the group was the independent variable. A one-way ANOVA was employed to determine the differences between groups.
Chapter 4: Results

Subjects missed an average of 109.73 minutes of data while participating in this study, regardless of group. Minutes missed ranged from 320.43 to 29.29 minutes. During the weekdays, participants missed an average of 109.91 minutes; on the weekends they missed 102.31 minutes. Participants wore their pedometers for an average of 14.26 hours during the study. They wore it an average of 14.19 hours during the weekdays and 14.29 hours on the weekend. Using data from the accelerometer, participants were awake for an average of 15.95 hours a day. During the weekdays subjects were awake for an average of 15.85 hours, and on the weekends they were awake for an average 16.12 hours per day. During these hours, individuals walked an average of 8,942.56 steps. Participants walked 9,407.75 steps during weekdays, and 7,709.08 steps on weekend days. Table 2 provides descriptive information for minutes missed, steps per day, hour’s participants wore the pedometer and hour’s participants were awake.

Table 2. Descriptive Data minutes missed, steps per day, hours worn, and hours awake.

<table>
<thead>
<tr>
<th></th>
<th>Minutes missed</th>
<th>Steps per day</th>
<th>Hours Worn</th>
<th>Hours Awake</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Avg. Total</td>
<td>320.43</td>
<td>97.14</td>
<td>8,942.56</td>
<td>104.02</td>
</tr>
<tr>
<td>Avg. WD</td>
<td>109.91</td>
<td>105.65</td>
<td>9,407.75</td>
<td>112.05</td>
</tr>
<tr>
<td>Avg. WE</td>
<td>102.31</td>
<td>112.14</td>
<td>7,709.08</td>
<td>139.50</td>
</tr>
</tbody>
</table>

Note: WD: week day, WE: Weekend day
The first research question was, what percent of time participant’s would wear pedometers when following the popular method of wearing pedometers during participant’s time awake. To do this, missed time was calculated. Participant’s mean time awake was 15.98 hours, ranging from 12.43 to 18.17 hours per day. The overall percentage of time participants did not wear the pedometer belt while they were awake was 11.08% (SD=9.52%) 95% CI [6.34%, 15.81%] ranging from 3.31% to 34.98%.

The experimental group missed 7.50% (SD=4.06%), ranging from 3.13% to 16.73% of their total awake time, 95% CI [4.38%, 10.62%], where the control group missed 14.66% (SD=12.14) ranging from 3.22% to 34.98% of their total awake time, 95% CI [5.33%, 23.99%]. Data was further broken down into weekday and weekends. The average percentage of missed awake time on week days for both groups was 10.80% (SD=10.31) ranging from 3.38% to 38.44%, 95% CI [5.66%, 15.92%]. During the weekdays the experimental group missed 7.35% (SD=4.25%) of their awake time, with the minimum missed being 3.57% and the maximum missed being 17.91% of their day, 95% CI [4.09%, 10.62%]. The control group missed 14.23% (SD=13.47%) of their weekdays ranging from 3.38% to 38.44%, 95% CI [3.88%, 24.58%]. During the weekend, the experimental group missed 7.25% (SD=5.09). The minimum awake time missed was 2.03%, and the maximum was 14.76%. The control group missed 14.15% (SD=13.10%) ranging from 2.03% to 36.88%, 95% CI [3.39%, 15.92%]. The total weekend missed time
for the sample was 10.27% (SD=10.27), 95% CI [5.59%, 15.81%]. There was no scientifically significant differences between the groups, $F(1,16) = 2.82$, $p > 0.05$.

The second research question addressed whether certain characteristics could predict any patterns of missing data. The results of a multiple regression indicated the number of daily steps, body mass index, group (experimental vs. control), and gender did not significantly predict the amount of missing data ($R=0.69$). The four predictors we examined explained approximately 48% of the variance of missing data. However, when we look at individual characteristics, average steps was the only variable that showed a significant negative effect at predicting missing time ($\beta = -0.61$, $p<0.05$). There was a negative association between number of steps per day and amount of missing data.

Table 3. Individual Characteristics and Missing Data

<table>
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<td>-0.607</td>
<td>-2.736*</td>
</tr>
</tbody>
</table>

Note * $p < .05$

The final research question asked about the effects of the use of a pedometer log. The mean amount of missing time for the entire sample was 111.76 minutes (SD=97.11), 95% CI [61.83, 161.69]. The mean amount of
missing minutes for the experimental group was 72.44 minutes, (SD=38.51), 95% CI [42.84, 102.05]. The total sample wore the pedometer belt for a mean of 14.26 hours (SD=1.73), 95% CI [13.37, 15.54]. The mean amount of missing minutes for the control group was 155.98 (SD=125.06), 95% CI [51.43, 260.53]. When looking at average amount of hours the participants wore the pedometer belt, the experimental group wore it for 14.48 hours (SD=1.81), 95% CI [13.06, 15.82] and the control group wore it for 14.07 (SD=1.76), 95% CI [12.59, 15.54].

An ANOVA was conducted to compare the effects of a pedometer log between the control group and the experimental group. There was no significance between the groups when looking at the average amount of hours the pedometer was worn, \( F(1,15)=0.186 \) \( p>0.05 \). An ANOVA comparing the effects of a pedometer log on weekends and weekdays was also conducted \( F(1,15)=0.180 \) \( p>0.05 \), and \( F(1,15)=0.072 \) \( p>0.05 \) respectively. There was no significant difference between the pedometer log and no pedometer log conditions.

The participants in the experimental group were awake for a mean time of 15.64 hours (SD=1.72) 95% CI [14.32, 16.97], the control group for 16.37 (SD=1.03) hours, 95% CI [15.50, 17.23], and the total sample for 15.98 hours (SD=1.45), 95% CI [15.24, 16.72]. Participant’s amount of awake time was similar between the control and experimental groups, with a total mean of 15.98 hours, 15.85 hours during weekdays, and 16.24 hours on weekends.
Chapter 5: Discussion

There is no disputing physical activity is an integral part in maintaining a healthy lifestyle. A physically active lifestyle can help prevent disease, obesity, and a multitude of other healthcare issues (Tudor-Locke, Burton, & Brown, 2009). In order to understand the amount of physical activity that is necessary to sustain a healthy lifestyle, there should be a standard method being measuring physical activity and outcome measures. This study examined the popular methodology behind measuring physical activity. Researchers have developed a method for measuring activity in a controlled setting; however, the method behind measuring physical activity in a free-living condition does not have a specific standard protocol. Researchers in the past have instructed participants to put on the pedometer when they wake up in the morning, and take it off when they go to bed, and also take it off during showering and water based activities; with assumption that participants will comply with the instruction and missing data are random.

We hypothesized people would miss a significant amount of physical activity during the study. For instance, a participant would get up in the morning and walk around before putting on the clothes he or she is going to wear later. Participants in this study missed a mean of 11% of his or her time awake per day throughout the week. When looking further into this 11%, participants missed almost two hours a day. The group with a pedometer log missed a mean of 72.44 minutes, slightly over one hour. Though it is not
statistically significant, the group without a log missed over double what the experimental group missed, 155.98 minutes (2.58 hours). Although it may be overestimation, we estimated the approximate number of steps the participants potentially took during the missing period by the total number of steps per day divided by hours of wearing time. Based on calculations, the sample missed an average of 1,175 steps per day, ranging from 81.09 steps to 3,803.24 steps per day. The experimental group missed an average of 1,510.51 steps per day, ranging from 168.85 to 3,803 average steps per day. Interestingly, the control group missed an average of 709.27 steps per day, ranging from 81.09 to 2,392.96 steps per day. This suggests that even though the control group missed more minutes of their day, the experimental group was more physically active.

A previous study examining long term physical activity noted that to be considered a day of measurement, pedometers must be worn for approximately 10 hours a day (Pelcolva, Walid, & Vasickova, 2010). Pedometer belts were worn for a mean of 14.26 hours a day. This held true for both weekdays (14.52 hours) and weekends (14.36 hours). Another study concluded that after 14 hours, physical activity levels could be predicted reliably (Thuy, et al., 2011). Multiple studies observed that when following the popular method behind measuring physical activity, participants wore their pedometers for between 13.4 and 14.9 hours (Leenders, Sherman & Nagaraja, 2000; Thuy, Blizzard,
Schmidt, Magnussen, Hansen, & Dwyer, 2011). This falls within the mean amount of hour’s participants in the present study wore their pedometer belts.

Individual characteristics were examined to determine if any had a correlation with missing data, or if missing data was not random. Average steps, body mass index (BMI), study group and gender could essentially predict 48% of total missing data (R=0.69). However, the only characteristic that was shown to be significant was average daily steps (level of physical activity). There was a negative relationship between average steps and the missing minutes. This may indicate that missing data is not random. There are two possible explanations of this indication. First, it suggests that people who had higher levels of pedometer assessed physical activity are more likely to be more compliant to this method of measuring physical activity. This finding is in agreement with a previous study that also suggested that people who are more active are more diligent when participating in studies involving a pedometer (Tudor-Locke, et al, 2001). Tudor-Locke, et al (2001) reported there was a negative relationship between pedometer steps per day and body mass index. This could mean individuals with a higher BMI walk fewer steps per day than someone with a lower BMI. In the study at hand, group classification and BMI also had a negative relationship between missing data, a higher BMI indicated more steps per day missing, however it was not significant. This would then, suggest that people with a higher BMI would wear their pedometer less hours per day. Another possibility is the negative
correlation between the two variables is due to the logic that individuals who wear pedometers for a longer period with inherently record more steps per their day. However, this possibility may need to be dismissed since there is no statistical significance between these characteristics and missing minutes.

The third research question addressed the effects of using a log to write down when participants put on and took off the pedometer. The negative relationship between missing minutes and group suggest that subjects in the experimental group missed less time than a participant in the control group. People in the control group missed double the minute’s participants in the experimental group missed, however, this could possibly be explained by innate punctuality of an individual. Tudor-Locke, et al. (2001) noted that there is an increase in the utility of pedometers with the additional use of a self-report log, much like the pedometer that was employed with the experimental group. A study by Rooney, Smalley, Larson, and Havens (2003) suggested that when using a physical activity log in addition to wearing a pedometer, participants exhibited higher levels of self-efficacy. Participants in this study also set higher walking (step) goals for themselves when using the log as an intervention aid.

Limitations of this study include the small sample group used. Participants were recruited from a convenience sample from a college-based town in the Pacific Northwest only. Some physical activity could have been potentially missed due to the limitations of the physical activity-monitoring
device. These could include water based activities or riding a bike. Though there was no significance between using a pedometer log when wearing a pedometer and not, lack of significance could be due to the small sample size.
Chapter 6: Conclusion

The purpose of this study was to examine the accuracy of common methods used in measuring physical activity using a pedometer. Though there were no significant differences between using a pedometer log when wearing a pedometer and not, a lack of significance could be due to the small sample size. Also, this study found that physical activity level does influence wear time of pedometers.

Although there were differences between data from the experimental and control groups, no statistical differences between the two groups were found on wearing time, and the amount of missed data. Considering a large variability in dependent variables, future study with a larger sample is needed to determine if characteristics influence pedometer wear time, and to see if a pedometer log can increase pedometer study compliance. There is still missing data that should be further investigated and the method of gathering physical activity information should constantly be challenged. Standard deviations in groups were extremely large; examining this could be beneficial.

Further study could include examining the effects of other individual characteristics including profession, status in school (full time, part time), or possibly even individuals with children and without children. It would also be interesting to involve an intervention portion of the study, to examine the effects of goal setting on pedometer wearing compliance. It could be logical to suggest that individuals in an intervention study would adhere to the
instructions of a study if there is a goal set in place, whether is was self-
determined or if a researcher set the parameters.

Motivation of wearing the pedometer could also be examined, for
example, is the person trying to lose weight, are they trying to be more active?
These motivators either intrinsic or extrinsic could significantly increase
protocol adherence.
Bibliography


Appendix A—IRB Approval

NOTIFICATION OF APPROVAL

April 20, 2012

Principal Investigator: Joon-ho Yoo, PhD
Department: Biological & Population Health Sciences

Study Team Members:
Student Researcher: Caityn Elliot
Study Number: 5213
Study Title: Measuring Pedometer Accuracy in Free Living Conditions
Funding Source: Internal
Funding Proposal #: In Grant/Contract:
Submission Type: Initial Application received 02/20/2012
Review Category: Expedited
Waiver(s): Waiver of Informed Consent
Risk Level for Children: N/A

Category Number: 7
Number of Participants: Do not exceed without prior IRB Approval
Number: 40

The above referenced study was reviewed and approved by the OSU Institutional Review Board (IRB).

Approval Date: 04/19/2012
Expiration Date: 04/18/2013

Annual continuing review applications are due at least 30 days prior to expiration date.

Documents included in this review:
☑ Protocol
☑ Consent forms
☑ Asent forms
☑ Alternative Consent
☑ Letters of support
☑ Recruiting tools
☑ Test instruments
☑ Attachment A: Radiation
☑ Attachment B: Human materials
☑ Project revision(s)
☑ Grant/contract
☑ Other: debriefing script, eligibility screening

Comments: A waiver of informed consent has been granted under 45CFR46.115(d) because this study involves deception. Participants are debriefed upon completion of the study in accordance with the IRB’s policy on deception in research.

Principal Investigator responsibilities for fulfilling the requirements of approval:

☑ All study team members should be kept informed of the status of the research.
☐ Any changes to the research must be submitted to the IRB for review and approval prior to the activation of the changes. This includes, but is not limited to, increasing the number of subjects to be enrolled.
☐ Reports of unanticipated problems involving risks to participants or others must be submitted to the IRB within three calendar days.
☐ Only consent forms with a valid approval stamp may be presented to participants.
☐ Submit a continuing review application or final report to the IRB for review at least four weeks prior to the expiration date. Failure to submit a continuing review application prior to the expiration date will result in termination of the research, discontinuation of enrollment of participants, and the submission of a new application to the IRB.

If you have any questions, please contact the IRB Office at IRB@oregonstate.edu or by phone at (541) 737-8001.

1 Where parental permission is to be obtained, the IRB may find that the permission of one parent is sufficient for research to be conducted under §46.404 or §46.401. Where research is covered by §§46.404 and 46.477 and permission is to be obtained from parents, both parents must give their permission unless one parent is deceased, unknown, incompetent, or not reasonably available, or when only one parent has legal responsibility for the care and custody of the child.

IRB Form v.01/2012
Appendix B—Eligibility Screening

The following questions must be answered in order to meet the inclusion criteria previously outlined. If yes, please indicate which injury and side of body the injury is on.

1. Are you over the age of 18?
   
   NO: _________
   YES: _________
   ** If no, participant is not eligible, and further screening is not necessary.

2. Are you currently recovering from any lower extremity orthopedic injury including, but not limited to ankle, foot, hip or knee injuries?
   
   NO: _________
   YES: ________________________________________________________
   ** If yes, participant is not eligible, and further screening is not necessary.

3. Are you aware of any leg length discrepancy?
   
   NO: ________
   YES: ________________________________________________________
   ** If yes, participant is not eligible, and further screening is not necessary.

4. Do you currently walk with a limp when wearing shoes?
   
   NO: ________
   YES: ________________________________________________________
   ** If no, participant is not eligible, and further screening is not necessary.

5. Do you currently walk with a limp when walking barefoot?
   
   NO: ________
   YES: ________________________________________________________
   ** If no, participant is not eligible, and further screening is not necessary.
Appendix C—Pedometer Log

Please record the times you put on your pedometer in the morning, and every time you take it off or put it back on.

<table>
<thead>
<tr>
<th>Days</th>
<th>Time on</th>
<th>Time off</th>
<th>Time on</th>
<th>Time off</th>
<th>Time on</th>
<th>Time off</th>
<th>Time on</th>
<th>Time off</th>
<th>Time on</th>
</tr>
</thead>
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<td>Day 1 (Example)</td>
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<tr>
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