VALIDATION OF MODERATE-TO-VIGOROUS PHYSICAL ACTIVITY PEDOMETERS

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ABSTRACT

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The objective of this study was to determine the validity of the Walk4Life model MVP 4 Function Digital Pedometer for measuring moderate to vigorous physical activity (MVPA). Sixty-five (38 female, 27 male) college students, age 18 years and older (*M* age = 20.17 years, *SD* = 4.08), volunteered for the study. Preliminary data collection included age, resting heart rate, height, body weight, body mass index (BMI), and gender. Each participant wore a pedometer and a Polar model T31 heart rate monitor to determine their MVPA steps per minute (SPM) threshold and to measure their heart rates during the treadmill tests. Manual and pedometer step counts were repeated and compared for 40 (17 male, 23 female) participants to establish step count accuracy and reliability in determining SPM. MVPA pedometer recordings were compared to the amount of time spent in their MVPA heart rate zone. The System for Observing Fitness Instruction Time (SOFIT) (McKenzie, Sallis, & Nader, 1991) instrument was used to code MVPA time during a Disc Lacrosse activity lesson and compared to MVPA pedometer readings during the direct observation portion of the study. Manually counted step counts did not significantly differ from pedometer recorded counts ($p = .30$), and pedometer recorded counts from the repeated trials were strongly and positively correlated ($r = .99$).

Pedometers tended to overestimate MVPA at lower speeds (*M* Absolute Error (AE) = -26.55) and underestimate MVPA at higher speeds (*M* AE= 23.53) during the treadmill tests. Neither gender (*p*= .721) nor BMI (*p*= .664) had a significant effect on absolute error. Pedometer estimates of MVPA significantly differed from that of the SOFIT (*p*= .012). Results yielded a significant effect for gender (*p*= .020) and BMI (*p*= .041) during direct observation. Walk4Life MVP pedometers are accurate and reliable for measuring steps, but may not be recommended for use by researchers to measure MVPA time due to estimation errors. Practitioners may find these pedometers useful for estimating MVPA because they are less arduous than direct observation methods such as the SOFIT.

Many Americans are overweight or obese. In fact, about 68% of adults in the United States are overweight or obese (Flegal, Carroll, Ogden, & Curtin, 2010), and 31.9% of children and adolescents exhibit a high body mass index (BMI) (Ogden, Carroll, & Flegal, 2008). With such a high prevalence of overweight and obesity in both adults and children, it is clear that action should be taken to decrease overweight and obesity rates. One possible way to decrease overweight and obesity rates is to increase daily caloric expenditure through physical activity. Research has shown that pedometers and accelerometers can be worn as a motivational tool to increase physical activity, and thus caloric expenditure (Pangrazi, Beighle, & Sidman, 2007).

Many people have benefited from the use of pedometers. Overweight and obese adults (Pal, Cheng, Egger, Binns, & Donovan, 2009), older adults (Croteau & Richeson, 2005; Croteau, Richeson, Farmer, & Jones, 2007), sedentary adults (Chan, Ryan, & Tudor-Locke, 2004), college students (Jackson & Howton, 2008), and children (Beets, Eilert, Pitetti, & Foley, 2006) have increased their activity levels through participation in pedometer physical activity interventions. Studies have also suggested health benefits from pedometer programs, including lowered systolic blood pressure (Pal et al., 2009), weight, BMI, waist girth, and resting heart rate (Chan, Ryan, & Tudor-Locke, 2004).

A pedometer is a motion-sensor device that is commonly used as an objective assessment instrument of physical activity. Most pedometers are attached at the waist to either the waistband of a user’s pants, or an elastic pedometer belt. They are unobtrusive, simple to use, lightweight, and relatively inexpensive, making them accessible for many children and adults. There are two main types of pedometers with different internal mechanisms.

The most common type of pedometer consists of a horizontal spring-lever arm that moves with vertical acceleration of the hips during ambulation. This movement opens and closes an electrical circuit; the lever arm causes an electrical contact and registers a step. Another type is a piezoelectric pedometer, which uses a piezoelectric mechanism with a horizontal cantilevered beam with a small weight on the end (Crouter, Schneider, and Bassett, 2005). When subjected to acceleration, the weight compresses a piezoelectric crystal, generating voltage proportional to the acceleration, and the voltage oscillations are used to record steps. This type of pedometer is not affected by pedometer tilt, and therefore may be less prone to error than swing arm pedometers. They are also more sensitive to vertical accelerations, meaning that it can record steps more accurately in slow walking than spring-levered pedometers (Crouter, Schneider, Karabulut, & Bassett, 2003).

There are many variables that can affect pedometer accuracy. Several studies have shown that walking speed can affect pedometer accuracy. Melanson et al. (2004), and Grant, Dall, Mitchell, and Granat (2008) found that pedometers were accurate at fast walking speeds, but were less accurate at slower speeds. Grant et al. (2008) and Cyarto, Myers, and Tudor-Locke (2004) state that for this reason pedometers are not an accurate method of assessment of activity levels for frail, institutionalized older adults, or for slow walking speeds. Activity type may also affect pedometer accuracy.

Pedometers do not accurately measure differences in energy cost related to isometric contractions, upper body movements (Montoye, 2000), or differences in intensity based on added weight bearing, gradient or incline (Hendelman, Miller, Baggett, Debold, & Freedson, 2000). Step counts will not reflect the additional energy expenditures in those activities because they generally do not involve an increased number of vertical accelerative hip movements. Pedometers also are not recommended for measuring certain locomotor movements such as skipping, sliding, or galloping (Smith & Schroeder, 2008; 2010). Consumers and practitioners should be aware that pedometers and accelerometers may not be appropriate for measuring intensity in activities other than bipedal movement such as walking, hopping, or running on flat and firm, solid surfaces.

Another concern is that body fat may affect pedometer accuracy. Pedometers must be held in a vertical plane in order to measure vertical accelerations accurately. Tudor-Locke, Williams, Reis, and Pluto (2002) suggested that excessive abdominal adiposity may interfere with appropriate pedometer placement or dampen the force of vertical acceleration, resulting in inaccurate measurements. Pedometer tilt angle (Duncan, Schofield, Duncan, & Hinckson, 2007), or walking speed (Melanson et al., 2004), may be stronger determinants in step count accuracy than BMI, waist circumference, or body fat percentage. To reduce the likelihood of pedometer tilt, pedometers should not be attached to loose clothing waistbands (Duncan et al., 2007). In addition to personal assessments, pedometer accuracy has been assessed in clinical research with some types of pedometers shown to be more accurate than others.

Piezoelectric pedometers very likely offer more accurate assessments than spring-levered pedometers for overweight or obese individuals (Crouter, Schneider, & Bassett, 2005). Duncan et al. (2007) measured the effect of body composition on pedometer accuracy in children, while other studies have focused on adults with Down syndrome (Pitchford, 2009), community-dwelling older adults (Grant et al., 2008), and nursing home residents (Cyarto, Myers, & Tudor-Locke, 2004). The results of these studies suggest that while spring-levered pedometers are accurate for use with the general population, piezoelectric pedometers may be more beneficial for use with special populations such as adults with Down syndrome, overweight or obese individuals, or frail, institutionalized individuals. Applied research has largely focused on whether pedometers are appropriate for use outside of clinical or laboratory settings.

Scruggs, Mungen, and Oh (2010) indicated that two important components of a quality physical education program are effectively involving students in moderate-to-vigorous physical activity (MVPA) for at least 50% of class time, as well as assessment of physical activity in physical education. They suggest that pedometers that measure MVPA may be effective in accomplishing these goals. Both Scruggs et al. (2010), and Scruggs, Beveridge, Watson, & Clocksin (2005) compared pedometer step counts to a validated instrument known as the System for Observing Fitness Instruction Time (SOFIT) (McKenzie, Sallis, & Nader, 1991), to determine the accuracy of using pedometers to estimate moderate- to- vigorous physical activity (MVPA) participation time. Scruggs et al. (2003) used a modified SOFIT when conducting a similar study, an instrument that was used for the direct observation portion of the present study. These studies suggest that physical educators could use pedometers to accurately evaluate how long their students spend in MVPA and determine whether their program is sufficiently active.

Pedometers provide an objective assessment and motivational tool that is accurate for use with most populations. While piezoelectric pedometers may be the most accurate choice for use with special populations, there are benefits to using an inexpensive swing-arm pedometer for the general population. For a detailed comparison of pedometers and their accuracy, see Table 1.0. The present study focuses on the validity of the Walk4Life model MVP pedometer, the only available swing-arm pedometer that claims to measure MVPA.

Method

Participants

The participants in this study were 65 (38 female, 27 male) college students (*M* age = 20.17 years, *SD* = 4.08) recruited from a university health course. All participants completed the treadmill tests. Forty participants (17 male, 23 female) were included in the pedometer reliability trial, and 58 participants (34 female, 24 male) completed the direct observation. Participants were informed that participation in the study was optional and would not affect their grade in the course. All participants were at least 18 years of age and signed a consent form prior to data collection. The research protocol was approved by the university's institutional human subjects review board.

Procedures

Each participant's height and weight were recorded using a Detecto model 339 scale with height rod and data was used to calculate BMI (*M*= 26.93, *SD*= 7.67). After sitting for a period of ten minutes, each participant's resting heart rate (*M*= 75.47 bpm, *SD*= 11.35) was taken by a trained investigator to use for the calculation of target heart rate zone using the Karvonen formula (American College of Sports Medicine [ACSM], 2010). Each participant's moderate-to-vigorous physical activity (MVPA) intensity threshold was calculated based on the American College of Sports Medicine (ACSM, 2010) recommended ≥40% of heart rate reserve (*M*= 125.21 bpm, *SD*= 6.87).

Each participant was assigned a Walk4Life model MVP digital pedometer to use for the duration of the study. The model MVP shares the same internal swing-arm mechanism as the model Walk4Life LS2525 and estimates MVPA based on a steps-per-minute threshold. Once determined, the pedometer was calibrated by entering each participant's threshold into the pedometer. For each second a person walks at or above that stepping pace, the pedometer registers the time as MVPA. When a person walks slower than the steps per minute threshold, the time is accumulated as activity time. In addition to the MVP pedometer, participants wore Polar model T31 heart rate monitors during the treadmill tests. The Polar model T31 was chosen because it has been shown to accurately measure heart rate (Radespiel-Troger, Rauh, Mahlke, Gottschalk, & Muck-Weymann, 2003).

Treadmill Tests

Pedometer calibration. Each participant began walking on a Life Fitness Model 93T treadmill at two miles per hour for a five minute bout of exercise to become acclimated to the treadmill and to warm up prior to exercise. Following the warm up, the treadmill speed was increased in one-half mile per hour per minute increments until the participant reached their MVPA threshold as demonstrated by achievement of ≥ 40% of heart rate reserve as shown on the heart rate monitor. The participants remained at their target treadmill speed (M= 3.37, SD= .41) for five minutes while a trained investigator carefully monitored the participant's heart rate and recorded the target treadmill speed.

At the completion of the five minute bout, the participants stepped onto the sides of the treadmill and an investigator attached the MVP pedometer to the participant's waistband in line with the posterior midline of the right thigh. Careful attention was paid to pedometer placement to avoid pedometer tilt. The participant stepped back onto the treadmill at their target speed for a bout of one minute. At the end of one minute, the participant stepped to the sides of the treadmill and an investigator removed the pedometer. The number of steps were recorded and entered into the pedometer as the steps-per-minute threshold. The pedometer step count was reset and an investigator reattached the pedometer to the participant's waistband. The number of steps during the one minute bout were also manually counted and recorded by the trained investigator. As a measure of reliability, forty subjects (17 male, 23 female) participated in a second, one-minute bout to determine if the pedometer recorded the same number of steps as a measure of reliability.

Estimating MVPA time. Each participant then stepped back on to the treadmill at a speed of one-half mile per hour slower than their target speed for a bout of four minutes. During this time, an investigator continually monitored heart rate to ensure participants were below their target heart rate threshold. At the end of four minutes, the participant stepped to the sides of the treadmill and an investigator noted the MVPA time according to the pedometer. Each participant then stepped back on to the treadmill at a speed of one-half mile per hour faster than his/her target speed for a bout of four minutes. During this time, an investigator continually monitored heart rate to ensure participants were at or above their target heart rate zone. At no time was the treadmill speed fast enough for a participant to request that he/she run rather than walk and at no time did a participant's heart rate decrease below their target heart rate threshold. At the end of four minutes, the participant stepped to the sides of the treadmill and an investigator noted the MVPA time according to the pedometer. After the completion of the two four-minute exercise bouts, an investigator removed the pedometer and participants walked at a self-selected speed for five minutes to cool down.

Direct Observation

One week after the completion of the treadmill tests participants took part in a 30 minute, game-like activity session in two gymnasiums. Seven participants that completed the treadmill tests were absent during the activity session resulting in 58 participants (34 female, 24 male). The activity was a modified version of Ultimate® called Disc Lacrosse that primarily involved walking and running on a flat surface. Participants wore numbered jerseys that corresponded with their assigned pedometer. Each participant's steps-per minute-threshold entered into the pedometer during the treadmill tests were checked and MVPA times reset to zero prior to the start of the activity session. An investigator attached a Walk4Life model MVP pedometer to each participant's waistband in line with the posterior midline of the right thigh. Again, careful attention was paid to pedometer placement to avoid pedometer tilt. Two Canon model GL1 digital video cameras mounted on tripods were positioned at opposite ends of each gymnasium to record the session. At the completion of the activity session, each participant's MVPA time according to his/her pedometer was recorded.

Two trained investigators coded each participant's activity time using the System for Observing Fitness Instruction Time (SOFIT) (McKenzie, Sallis, & Nader, 1991). The SOFIT was used because it has been shown to be a valid and reliable instrument for estimating MVPA time during activity sessions and has been used in conjunction with pedometry (Scruggs et al., 2003). The three phase observation system was reduced to a single three-category (i.e., 1= sedentary, 2= walking, 3= very active) coding system. Following analysis, codes 2 and 3 were counted towards MVPA. An inter coder agreement level of .95 was established prior to the start of coding.

Design

The first hypothesis postulated that the Walk4Life model MVP pedometer would accurately and reliably record step counts. To test this, a dependent (paired sample) t-test was conducted on the manually counted steps and the pedometer recorded steps during the one minute exercise bout. Also, a dependent (paired sample) t-test was conducted on the first and second pedometer recorded steps using the same pedometer and the same participant during the one minute exercise bout.

The second hypothesis was that pedometer MVPA estimates during the two four-minute treadmill tests would not significantly differ from expected MVPA. Absolute error (AE) was calculated (expected minus actual) and used as the dependent variable. AE has been used in other pedometer accuracy studies, such as Smith and Schroeder (2010), as well as McMinn, Rowe, Stark, and Nicol (2010). Using absolute percentage error was problematic because the expected MVPA time during the slower test (below MVPA threshold) was zero. The expected MVPA time during the faster test (at or above MVPA threshold) was four minutes. Gender was a variable of interest. BMI was a secondary variable of interest with a potential effect on the relationship between gender and AE. To test for gender effects and to control for BMI, a 2 (gender) x 2 (test) repeated measures analysis of covariance (ANCOVA) with BMI as a covariate was used. In this way, the design controlled for the effect of BMI.

The third hypothesis was that MVPA as estimated by the pedometers would not significantly differ from MVPA as estimated using the SOFIT. Again, gender was a variable of interest and BMI a secondary variable of interest. To test for gender effects and to control for BMI, a 2 (gender) x 2 (estimator) repeated measures ANCOVA with BMI as a covariate was used with MVPA time (in seconds) as the dependent variable.

An a priori alpha of .05 was set for all analyses and Bonferroni adjustments were used for all pairwise comparisons.

Results

Accuracy and Reliability

A dependent t-test indicated that manually counted steps (*M*= 121.56, *SD*= 10.27) did not significantly differ ($t(57) = -1.04$, $p = .30$) from pedometer recorded steps (*M*= 121.80, *SD*= 10.62). The paired sample correlation yielded a strong, positive correlation between manually counted and pedometer counted steps ($r = .989$). A second dependent t-test indicated that the first pedometer recorded steps from the first bout (*M*= 121.80, *SD*= 10.62) did not significantly differ ($t(39) = -1.17$, $p = .28$) from the second (*M*= 122.05, *SD*= 10.75). The paired sample correlation yielded a strong, positive correlation between the two trials ($r = .99$). The pedometers were shown to be both accurate and reliable at counting steps.

Treadmill Tests

Table 2 compares men and women during slow and fast treadmill tests. A 2 (gender) x 2 (test) repeated measures ANCOVA with BMI as a covariate did not indicate a significant effect for BMI ($F(1, 62) = .304$, $p = .664$, $\eta^2 = .003$) or gender ($F(1, 62) = 1.29$, $p = .721$, $\eta^2 = .002$). Pairwise comparisons indicated that women did not significantly differ from men on AE ($p = .721$). Levene's test was not significant, indicating that the assumption of homogeneity was not violated (slow $F(1, 63) = 1.12$, $p = .292$; fast $F(1, 63) = .027$, $p = .869$). Neither gender nor BMI had an effect on AE. Figure 1 depicts a scatterplot of AE against BMI. In general, the pedometers tended to overestimate MVPA at lower speeds (*M* AE= -26.55) and underestimate MVPA at higher speeds (*M* AE= 23.53).

Direct Observation

Table 3 outlines MVPA time by estimator (pedometer vs. SOFIT). A 2 (gender) x 2 (estimator) repeated measures ANCOVA with BMI as a covariate yielded a significant effect for gender (F(1, 55) = 5.734, p= .020, η^2 = .094) and for BMI (F(1, 55) = 4.379, p= .041, η^2 =.079). Pairwise comparisons indicated that women were significantly different from men on MVPA (p= .020) and that pedometer estimates were significantly different from that of the SOFIT (p= .012). Levene’s test was not significant, indicating that the assumption of homogeneity was not violated (pedometer F(1, 56)= .357, p= .553; SOFIT F(1, 56)= .357, p= .573). A follow-up Pearson product-moment correlation yielded a strong, positive correlation between estimates of MVPA by the pedometers and the SOFIT (r = .99). Figure 2 depicts a scatterplot of MVPA time against BMI for women and men. In general, the SOFIT (*M*= 427.62, *SD*= 262.28) provided a more generous measure of MVPA than the pedometers (*M*= 428.62, *SD*= 247.20), particularly in women (pedometer *M*= 360.18, *SD*= 266.43; SOFIT *M*= 367.35, *SD*= 260.64).

Discussion

The purpose of this study was to determine whether Walk4Life MVP pedometers accurately measure moderate- to-vigorous physical activity (MVPA) in clinical research and practical activity settings. These pedometers are intended to measure MVPA through the use of a SPM threshold. When the user walks at a speed higher than their selected threshold, the pedometer records the length of time as MVPA. The pedometer was assessed through the conduction of treadmill tests and direct observations in a physical activity setting. Results indicate Walk4Life MVP pedometers provide an accurate and reliable measure for counting steps and are effective for practitioners to use to estimate MVPA time. However, these pedometers require some improvements before they can be used to assess MVPA time in research settings.

The pedometers were shown to be both an accurate and reliable tool for counting steps. This is consistent with previous research which has shown that pedometers, even ones that use an inexpensive swing-arm design, can be accurate at counting steps (Crouter, Schneider, & Bassett, 2005). Based on the results of this study, both researchers and practitioners could use the Walk4Life MVP to measure step counts. As for measuring MVPA, further investigation and potential design changes are warranted.

During treadmill testing, the pedometers overestimated MVPA time at speeds lower than the subjects' projected MVPA intensity zone when compared to manual measurements, and underestimated MVPA time at speeds higher than the subjects' minimum MVPA threshold during the treadmill tests when compared to manual measurements. Also, the results suggest that neither BMI nor gender had an effect on the pedometers' estimation of MVPA time. In this clinical setting, careful attention was paid to pedometer tilt and participants were continuously monitored to ensure that they were walking at their correct heart rate intensity. Perhaps the BMI/waist-to-hip ratio/body fat issue that often faces swing-arm pedometers was avoided through careful monitoring of pedometer placement. Estimation issues may instead be based on the pedometer's design.

The present study used a more objective means of calibration than recommended by the manufacturers. The manufacturer recommends that the user take a short 2-3 minute walk to warm up, clear all pedometer steps, attach the pedometer to the midline of the thigh, and then walk at a brisk pace for exactly one minute. At the end of the minute, the user enters the step count, rounding to the nearest interval of 10 (steps per minute). This method only takes a subjective assessment of MVPA into account, because the user determines what he or she feels is a brisk pace for them. The present study used a more objective assessment of MVPA by determining the user's MVPA using heart rate monitors. The fact that the Walk4Life MVP pedometer does not allow for an exact number of steps per minute threshold calibration may create a discrepancy between MVPA estimates. Suggestions for improving accuracy of the pedometers include changing the entry mode of the SPM threshold to allow for an exact step count or smaller intervals to reduce over or under estimation. It may be that, as with many swing-arm designs, the pedometers are more effective if they are used at fast walking speeds.

The results of this study suggest that pedometer MVPA estimates could differ significantly from direct observation instruments such as the SOFIT. Indeed, the SOFIT provided a more generous estimate of MVPA time than did the pedometers, especially in women. Gender and BMI also had an effect on pedometer accuracy during direct observation. These results suggest that the pedometers may be more useful for practitioners seeking an economical, quick, and uncomplicated method to estimate MVPA in physical activity settings than researchers in clinical settings.

During the direct observation phase of this study, men spent more time in MVPA than women. However, the relatively small differences between MVPA as estimated by the pedometers and MVPA as estimated by the SOFIT were likely more attributable to differences in BMI than differences in gender. This is consistent with previous research that has shown pedometers to be less accurate in overweight or obese individuals (Tudor-Locke, Williams, Reis, & Pluto, 2002; Duncan, Schofield, Duncan, & Hinckson, 2007; Melanson et al., 2004). Perhaps, as previous research has indicated (Crouter et al., 2005), waist-to-hip ratio can have a significant effect on pedometer accuracy. This research did not study waist-to-hip ratio or waist circumference influence on MVPA.

The MVP pedometer is comparable in accuracy to other lever-arm pedometers such as the New-Lifestyles: Digiwalker SW-200 (Grant et al. 2008), the Walk-4-Life:LS-2500 and Step Keeper: HSB-SKM (Melanson et al., 2004), and the Walk4Life, Inc.: W4L Pro (McClain, Hart, Getz, & Tudor-Locke, 2010) at counting steps. However, accelerometers, such as the Actigraph, may be more accurate for measuring MVPA time (Sirard, Trost, Pfeiffer, Dowda, & Pate, 2005).

In summary, the Walk4Life MVP pedometer appears to be accurate and reliable for measuring steps for both practitioners and researchers. As well, the MVP pedometer provides tangible benefits for practitioners in that they are not only economical, around 25 U.S. dollars each, but are a much less arduous assessment of MVPA time than the SOFIT. The SOFIT is a time-intensive direct observation method that typically takes up to two hours to evaluate a one-hour activity session and requires training to accurately assess student activity time. In summary, the sensible but substantive variation in estimating MVPA time by using the Walk4Life MVP may be overshadowed by the ease of use for practitioners as compared to the SOFIT and other means of direct observation. These pedometers may be useful for the general population as well as physical educators who are interested in a simple, fast, and reasonably valid method of measuring physical activity levels or participation.

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Appendix A: Review of Literature

Introduction to Pedometers

A pedometer is a motion-sensor device that is commonly used as an objective assessment of the amount of physical activity (Vries, Bakker, Hopman-Rock, Hirasing, & van Mechelen, 2006). Most pedometers are attached at the waist to either the waistband of a user's pants, or an elastic pedometer belt. They are unobtrusive, simple to use, lightweight, and relatively inexpensive, making them suitable for many children and adults. Pedometers have been used for several hundred years and have improved in accuracy, reliability and availability. Modern pedometers are much more accurate than the first pedometers.

According to Gibbs-Smith (1978), Leonardo da Vinci developed the principle behind the mechanical pedometer in the 15th century. The earliest pedometer consisted of a lever arm affixed to the user's thigh; when the lever arm moved back and forth during walking the gears rotated and counted steps. Early pedometers were also used to count steps to survey plots of land. Bassett and Strath (2002) and Montoye (2000) indicated that President Thomas Jefferson acquired a pedometer while in Paris, France, and used it to measure the distance to various Paris landmarks in steps. Afterward, more people in America began using pedometers. Several types of pedometers have been developed since the first pedometers were invented.

Older pedometers were gear-driven and mechanical, while newer versions are electronic. The most common type of pedometer consists of a horizontal spring-lever arm that moves with vertical acceleration of the hips during ambulation. This movement opens and closes an electrical circuit. The lever arm causes an electrical contact and registers a step. As described by Crouter, Schneider, and Bassett (2005), another main type is a piezoelectric pedometer, which uses a piezoelectric accelerometer mechanism with a horizontal cantilevered beam with a small weight on the end. When subjected to acceleration, the weight compresses a piezoelectric crystal, generating voltage proportional to the acceleration, and the voltage oscillations are used to record steps. This pedometer may not be as subject to influence of pedometer tilt, and therefore may be less likely to record errors. It is also more sensitive to vertical accelerations, meaning that it can record steps more accurately in slow walking than spring-levered pedometers (Crouter, Schneider, Karabulut, & Bassett, 2003).

Another type of motion-sensor measurement device is an accelerometer. Accelerometers are similar to pedometers, but are more detailed in measuring and recording physical activity (Zan et al., 2010). Some pedometers measure the number of steps taken in a certain period of time, estimate distance based on programmed stride length, and estimate calories, while accelerometers measure the intensity (sedentary, light, moderate, or vigorous) of the physical activity and energy expenditure. One advantage of pedometers is that they are, on average, less expensive ($20-50) than accelerometers ($100-500), and therefore more accessible to the general community and schools. Pedometers are comparable in accuracy of step count to accelerometers and the lower cost makes pedometers appealing to many consumers and researchers. Table 1 features a list of commonly used pedometers and their accuracy.

Factors That Affect Pedometer Accuracy

Walking Speed.

Several studies have shown that walking speed can affect pedometer accuracy. Melanson et al. (2004) studied 259 adults, aged 19-85 years, of varying weight and BMI range. Subjects walked down a corridor at a self-selected pace they felt was their normal speed, followed by their self-selected speed for a brisk walk. The researchers recorded the length of time it took them to walk the short initial distance, and then calculated normal and brisk walking speeds for each subject. Then, each subject wore a pedometer while walking on a treadmill for 10 minutes at their calculated speed. The pedometers significantly undercounted steps at walking speeds less than three miles per hour, but accurately assessed steps at greater walking speeds.

One study compared the levels of pedometer accuracy when measuring physical activity levels of nursing home residents with those of community-dwelling older adults (Cyarto, Myers, & Tudor-Locke, 2004). Researchers measured a 13-meter distance and instructed subjects to walk at three self-paced speeds. Actual steps were measured by a hand counter and compared to the pedometer step counts. Researchers also videotaped the walking trials for further verification use. Findings suggested that the pedometers consistently underestimated the step count of the nursing home residents and may not be accurate in quantifying physical activity in frail, institutionalized, older adults. However, the results show that pedometers may be accurately used with healthy community-dwelling older adults. Other studies have focused on the effects of walking speed on pedometer accuracy.

Grant, Dall, Mitchell, and Granat (2008) conducted research with community-dwelling older adult subjects in order to determine the accuracy of activity monitors to measure step number and cadence. Researchers fitted each subject with an accelerometer that attaches to the skin on the thigh with an adhesive pad. In addition, two different types of pedometers (Digiwalker SW-200, a spring-levered pedometer; NL-2000, a piezoelectric pedometer, both by New-Lifestyles, Inc.) were used to make comparisons. Each participant walked on a treadmill at five different speeds for five minutes at each speed. They rested while their pedometer counts were recorded and reset to zero before moving on to the next speed. The subjects then walked around a measured course on a university campus at three self-selected speeds. They completed one circuit of the course at each self-selected speed (normal, slow, and fast walking), for a total of three circuits. After each circuit, subjects sat down on a chair to rest, and their pedometer counts were recorded. All trials were videotaped for further review. The SW-200 was found to be the least accurate pedometer at slower speeds, while the NL-2000 registered less than a two-percent difference from the accelerometer in all but the slowest speed. While the accelerometer was accurate at all speeds, both pedometers were found to be most accurate at a fast walking speed, but undercounted steps at slow walking speeds. Other types of physical activity may affect pedometer accuracy.

Type of physical activity.

Pedometers have been validated for use in measuring bipedal locomotion, but have not been validated to measure other movement types. Montoye (2000) stated that pedometers do not accurately measure upper body movements. Pedometers and accelerometers do not accurately measure differences in energy cost related to isometric contractions, upper body movement, added weight bearing, or when walking on graded or soft surfaces. The step counts do not reflect those activities because they generally do not involve an increased number of vertical accelerative hip movements. Results from other studies support this finding.

Hendelman, Miller, Baggett, Debold, and Freedson (2000) conducted a study on the validity of accelerometry when assessing moderate intensity physical activity in the field. Subjects completed four activities at self-selected speeds while wearing one pedometer and two accelerometers. The researchers measured their energy expenditure with a portable metabolic system. They then compared the step counts and intensity measurements with the measured energy expenditure to determine whether the motion sensors accurately measured different modes of moderate-intensity activity. Results showed that the motion recorders did not accurately account for the difference in intensity of exercises related to upper body, or increased grade that would increase the heart rate and oxygen uptake levels to represent moderate-intensity exercise. Therefore, consumers and researchers should be aware that pedometers and accelerometers may not be appropriate for measuring intensity in activities other than bipedal movement on flat, firm, and solid surfaces.

Smith and Schroeder found that pedometer accuracy varied when fifth-grade students (2010) and college students (2008) were walking, galloping, skipping, and sliding. Although the step counts were closely correlated with the actual counts when subjects were walking or hopping, the count was inconsistent when measuring skipping, sliding, or galloping. While walking, the ground contact occurring with each step creates a vertical force at the hip and registers a count on the pedometer. Researchers hypothesized that the differences in the flight phase and force generation between lead and trail legs may be factors in the inaccurate calculation. The authors reasoned that if both legs generated the same amount of force, the pedometer step count would be similar to that of the actual count; however, since the two counts differed, it may be inferred that there is a difference in force generation. There was a statistically significant discrepancy between the actual count and pedometer step count for skipping, sliding, and galloping. Therefore, it may not be effective to use pedometers to measure these activities

Body composition.

Pedometers must be held in a vertical plane in order to measure vertical accelerations accurately. Tudor-Locke, Williams, Reis, and Pluto (2002) suggested that excessive abdominal adiposity may interfere with appropriate pedometer placement or dampen the force of vertical acceleration, resulting in inaccurate measurements. In addition, Abel et al. (2009) suggest that a high waist circumference may decrease pedometer accuracy. Tudor-Locke and Myers (2001) mention that obese users may also be uncomfortable with wearing some pedometers in their recommended placements or pedometers may fall off of individuals with excess abdominal adiposity, resulting in potential instrument loss or participant frustration.

Duncan, Schofield, Duncan, and Hinckson (2007) measured the effect of body composition on pedometer accuracy in children. Eighty-five subjects, ages 5-7 and 9-11 years old, walked on a treadmill for two minute bouts at three different speeds while wearing a spring-levered (Yamax SW-200) and a piezoelectric (New Lifestyles NL-2000) pedometer. An observer also recorded the actual number of steps with a hand counter. The authors found that body mass index, waist circumference, and body fat percentage did not significantly affect pedometer accuracy; the pedometer tilt angle was the strongest determinant in step count accuracy.

Researchers have also studied the effects of obesity on pedometer accuracy in adults. In a previously mentioned study, Melanson et al. (2004) found a correlation between BMI, weight, and pedometer bias. Researchers recorded each subject's weight and BMI, had subjects select their normal and brisk walking paces, and calculated their step count based on observations. The pedometer bias was overall positively correlated with BMI and weight. As BMI and weight measurements increased, there was a greater discrepancy between the actual step count and the pedometer step count. However, when researchers compared data by walking speed, there was no significant difference in pedometer accuracy between lean and obese individuals. This suggests that walking speed, rather than weight or BMI, was the most directly related factor in pedometer accuracy in this study. One reason for the correlation of BMI and weight with pedometer accuracy is that many of the obese individuals in the study selected slower walking speeds.

Crouter, Schneider, and Bassett (2005) studied the difference between spring-levered and piezoelectric pedometer accuracy for overweight and obese individuals. Forty subjects with an overweight or obese BMI classification walked on a treadmill at five different speeds in 3-minute stages. An observer used a hand counter to measure the actual steps taken. The researchers found that the spring-levered pedometer (Yamax Digiwalker SW-200) accuracy was negatively correlated with BMI, waist circumference, and pedometer tilt angle. However, the piezoelectric pedometer (New Lifestyles NL-2000) was not significantly affected by any of these variables. Therefore, a piezoelectric pedometer may be more beneficial for use in overweight or obese individuals. The pedometer tilt angle had more influence on the pedometer accuracy than BMI or weight alone. While adiposity may potentially affect the pedometer tilt angle, the angle may be affected by other variables as well.

As mentioned in an earlier study, Duncan et al. (2007) found that in children pedometer tilt angle was the strongest factor in pedometer accuracy, rather than waist circumference or BMI. The most probable reason is that over a third of the subjects had a large tilt angle as a result of attaching the pedometers to loose clothing waistbands. The lack of elasticity in the waistband frequently resulted in the pedometer tilting away from the vertical plane, thereby affecting the accuracy of the subject's step count. This study suggests that unsuitable clothing decreases pedometer accuracy, regardless of a child's body size, so it may be effective to use a firm elastic belt when utilizing pedometers to measure steps in children.

Pedometer placement.

Pedometer placement has been found to affect the detection of vertical acceleration during activity. Graser, Pangrazi, and Vincent (2007) conducted a study to determine the effects of waist placement on pedometer accuracy in normal, overweight, and obese children. Seventy-seven children aged 10 to 12 years wore five pedometers on the waistband of their pants and a belt. Placement sites included the navel (NV), anterior midline of the right thigh (AMT), right side (RS), posterior midline of the right thigh (PMT), and the middle of the back (MB). Each subject walked 100 steps on a treadmill at 3.0 miles per hour, while the researcher recorded the number of actual steps with a hand counter. Following the final step, the researcher read and recorded the step counts from each pedometer. Results showed that the RS, PMT, and MB placement sites were most accurate in measuring step counts on waistband tests for all weight classifications. While all three sites were accurate, the RS placement was most recommended because it may be easier to read the pedometer during activity.

There are many uses for pedometers in research and everyday physical activity monitoring. Troiano et al. (2007) used pedometers to gather activity level information in 2003-2004. Pedometers may be an effective way to increase the number of daily steps and promote physical activity in adults and young people because “it is a straightforward concept to understand and is non-threatening for children of all body sizes and physical abilities” (Duncan, Schofield, Duncan, and Hinckson, 2007, p. 420). Therefore, it may be part of an effective response to the problem of obesity and inactivity.

The Need to Increase Physical Activity and Reduce Obesity

Recent studies have indicated that many American adults and children are overweight or obese. In 2007-2008, researchers measured the height and weight of 5,555 adult men and women over 20 years old and found that a combined 68% of adults in the United States were overweight or obese (Flegal, Carroll, Ogden, & Curtin, 2010). Similarly, 31.9% of children and adolescents ages 2 to 19 exhibited a high body mass index for age (Ogden, Carroll, & Flegal, 2008). Obesity negatively affects children and one study indicated that obese children scored lower on a health-related quality of life questionnaire measuring physical, social, and school-related domains than their normal-weight counterparts (Pinhas-Hamiel, et al., 2006). With such a high prevalence of overweight and obesity in adults and children alike, it is clear that action should be taken to decrease the incidence of overweight and obesity.

One possible way to decrease the rate of overweight and obesity is to increase daily caloric expenditure through physical activity. A pedometer assessment of activity levels from 2003-2004 indicated only 42% of children 6-11 years old achieved the recommended 60 minutes of daily physical activity. Even fewer adolescents met this minimum standard, with only 8% performing 60 minutes of daily physical activity. Less than 5% of adults met the minimum recommendation of 30 minutes of daily moderate intensity daily exercise (Troiano et al., 2007). Moderate-to-vigorous physical activity (MVPA) is defined as physical activity at an intensity ≥ 40% of an individual's target heart rate zone (American College of Sports Medicine, 2010). Brisk walking at a speed that noticeably increases heart rate and breathing is the recommended minimum level for moderate-intensity physical activity (ACSM, 2010). In addition, MVPA must be at a minimum of 3-5 days per week in order to achieve and maintain health and fitness benefits.

In addition to increasing MVPA time, individuals should minimize their amount of daily sitting time. Many adults sit for the majority of their waking hours. Miller and Brown (2004) found that the average sitting time in working Australian adults is 9.4 hours per day, demonstrating that sedentary lifestyle is not limited to Americans. Subjects recorded their daily sitting time and wore pedometers at all times for one week, with the exception of when they showered, swam, or slept. They were encouraged to maintain their normal schedule for the course of the study. As hypothesized, researchers found a negative correlation between sitting time and daily step counts; the longer the subjects sat, the lower their step number. In addition to assessing physical activity, Pangrazi, Beighle, and Sidman (2007) suggested that one potential way to increase physical activity, and thus caloric expenditure, is through the use of pedometers and accelerometers.

Effects of Pedometer Use

Increased Physical Activity Levels in Adults.

Pal, Cheng, Egger, Binns, and Donovan (2009) found that overweight and obese women who used a pedometer increased their daily step count by 36% at the end of 12 weeks, compared with a control group who did not use a pedometer during the study. Although the experimental group received health benefits by lowering their systolic blood pressure, there were no significant differences in weight or body fat composition between the two groups at the end of the study. Although this study only consisted of a small sample of 26 overweight and obese middle aged women, other studies have suggested increased activity with pedometer use.

Croteau and Richeson (2005) studied the implementation of a 4-month pedometer-based physical activity program known as “A Matter of Health Walking Program” for older adults. As part of the program, 76 older adults aged 60-90 years old set personal goals, selected activities, and self-monitored their activity levels by wearing a pedometer. Over the course of four months, there was a significant increase in daily step count for the group as a whole, with a mean improvement of 1,518 daily steps. The results suggest this pedometer program was effective in increasing participants’ daily physical activity levels.

A similar study found that a 12-week pedometer program resulted in a significant increase in the daily step count of 147 community-dwelling adults 55-94 years of age (Croteau, Richeson, Farmer, & Jones, 2007). One half of the participants were enrolled in the program for the first 12 weeks, followed by a 12 week maintenance period, while the control group remained on a waiting list for the first 12 weeks, then participated in the program for the second 12 week period. The experimental group improved their daily step count by 13.1 % during the intervention and continued to increase their daily step counts by 12.4% during maintenance, resulting in a total increase of 27.2% over baseline step counts. The control group decreased their average step count by 7.5% over the control wait period, but increased their daily step counts by 33%, resulting in an improvement of 22.9% over the baseline measurements. This study suggests that pedometers may be beneficial for use in physical activity intervention programs for older adults. Still, it is important to consider potential factors that could affect the study results.

One potential limitation of this study was that subjects volunteered to participate in the program, and therefore may have been more motivated to improve their daily physical activity levels than other older adults. It is also notable that, similar to this study, some pedometer-based physical activity intervention programs involve goal-setting, meetings with peers, and other components and it is unknown how much these aspects influenced the results. One potential reason the experimental group demonstrated a further increase during the maintenance period was the knowledge of a follow-up meeting after the program completion; therefore, they may have been more motivated to continue increasing their daily step counts than if they were unaware of the follow-up session.

Studies have also demonstrated successful pedometer use with sedentary adults. Several studies of pedometer intervention programs have shown a significant increase in activity levels in sedentary adults. Sedentary workers enrolled in a 12-week pedometer-based physical activity intervention experienced an increase in daily physical activity as well as health benefits. Subjects were recruited from workplaces where most jobs were moderately to highly sedentary. A total of 106 subjects successfully completed the program. Prior to the program implementation, researchers collected baseline ambulatory activity data by finding the mean number of daily steps the participants took over the period of two workdays and one weekend day, as recorded by a sealed pedometer worn during waking hours, with the exception of any time spent in water. Researchers also recorded each subject's body weight, height, waist girth, heart rate, and blood pressure.

During each week of the pedometer intervention, participants set daily pedometer step goals and monitored their progress on a personal log. Researchers recorded post-program data for participant height, weight, waist girth, heart rate, and blood pressure, as well as mean daily step counts. Results showed significant decreases in weight, BMI, waist girth, and resting heart rate, as well as a significant increase in daily steps (Chan, Ryan, & Tudor-Locke, 2004).

Jackson and Howton (2008) conducted a study involving the use of pedometers in undergraduate college students. Subjects participated in a 12-week pedometer intervention which monitored their daily steps. Researchers compared average daily steps from the first week to the sixth week, and then to week 12. At the beginning of the intervention, 65% of the subjects were classified as sedentary or low-active, with a total group average of approximately 7,000 daily steps. By the sixth week, the daily step count averaged just below 9,000 steps, and at the end of week 12, participants had increased their average count to nearly 10,000 steps per day. Furthermore, only 25% of the subjects remained at a sedentary or low-activity level at the completion of the intervention.

Increased Physical Activity Levels in Children.

One study demonstrated a significant increase in physical activity levels in children who used pedometers. Beets, Eilert, Pitetti, and Foley (2006) found third through fifth grade students were reportedly more active when they wore a pedometer for seven days. Subjects wore unsealed pedometers for seven consecutive 24-hour time periods. Afterward, the children responded to a questionnaire asking whether they increased their activity behaviors, while the parents reported whether they observed an increase in their child's activity levels. Seventy percent of the children and almost half of the parents reported an activity change from wearing a pedometer.

One possible explanation for the difference in parent and child reports is that parents did not observe their children while they were at work or while the children were at school, so the activity levels may have been higher at other times during the day than those recorded. While this study suggests that pedometers may create a reactive response and provide incentive for children to be more active, it is unclear whether the children will maintain a higher activity level if they discontinue pedometer use.

Measuring Activity in Physical Education

Pedometers can be used to collect data to determine the effectiveness of physical activity programs and to develop statistics regarding children's participation in physical activity. Beighle, Morgan, Le Masurier, and Pangrazi (2006) used pedometers to assess physical activity in third-, fourth-, and fifth-grade children. They measured step counts and activity time during recess and outside-of-school to find out how often and for how long students are active during discretionary periods. Tudor-Locke, Lee, Morgan, Beighle, and Pangrazi (2006) conducted a similar study to assess sixth graders' participation in physical activity throughout the school day, based on pedometer readings taken before and after school, as well as following physical education, recess, and lunchtime. They found male subjects took significantly more steps per day than their female counterparts. Lunchtime physical activity was the greatest contributor to steps during the school day. Nearly half of daily steps were attributable to after-school activities.

Researchers have also studied preschoolers in order to gather pedometer accuracy data. Studies have focused on the use of pedometers in older children and adults, but few have tested the validity of pedometers for use in younger subjects. Oliver, Schofield, Kolt, and Schluter (2007) conducted a pedometer accuracy study with 13 3-5 year old children. During this study, subjects wore a pedometer and ambulated in a straight line for 29 meters using three levels of physical activity. These levels consisted of slow walking, normal walking, and running. Researchers compared the subjects' pedometer step counts to results from an instrument known as the Children's Activity Rating Scale (CARS), which is a direct observation approach, to determine if the results were statistically accurate. Results showed considerable variability in the ability of the pedometers to accurately predict physical activity. This may be affected by preschoolers' use of a wide base of support during ambulation, affecting the measurement of vertical acceleration. Although this is one of the first pedometer studies conducted with subjects of this age, there were several limitations to the study.

One limitation was that the CARS instrument was developed using energy expenditure, instead of physical activity, as a criterion. Therefore, it may not be an appropriate tool for comparing physical activity participation to pedometer counts measuring physical activity. This could account for some of the discrepancy between the two measurements used in the study. Another limitation of the study is that the direct observation protocol may have been subjective, resulting in a variance in accuracy. Based on the results of this study, pedometers may not be appropriate for research purposes with young children.

Pedometers have also been used to measure the effectiveness of physical education in encouraging movement. Scruggs, Mungen, and Oh (2010) indicated that two important components of a quality physical education program are effectively involving students in MVPA for at least 50% of class time, and assessment of physical activity in physical education. They suggest that pedometers that measure MVPA may be effective in carrying out these components. Scruggs, Mungen, and Oh (2010) recorded total steps of high school students during physical education classes and calculated steps per minute by dividing the total number of steps by lesson time. They compared the results to a validated instrument known as the System for Observing Fitness Instruction Time (SOFIT) (McKenzie, Sallis, & Nader, 1991), to determine the accuracy of using steps per minute to calculate MVPA participation time.

The SOFIT instrument measures student and teacher behaviors by direct observation. Every 10 seconds, the observer indicates what intensity of activity the students are performing, as well as the way teachers are instructing the class. Brisk walking is the recommended minimum level for moderate-intensity physical activity in children (Scruggs et al., 2003). SOFIT also identifies brisk walking as the minimum threshold of MVPA. A strong positive correlation of data from the study suggests that pedometers can be incorporated into physical education classes to accurately calculate

MVPA time in bipedal activities, such as walking or jogging. This method of analyzing physical education has also been used in additional studies.

A total of 257 first-through-fourth grade children participated in a study which quantified physical activity in physical education classes via pedometry (Scruggs, Beveridge, Watson, & Clocksin (2005). Students wore pedometers during physical education classes; the pedometer recordings were each compared to the SOFIT (McKenzie, Sallis, & Nader, 1991) instrument in order to determine whether the pedometers were accurate in measuring physical activity during the physical education lessons. After comparing the results from the SOFIT instrument with the mean steps per minute calculated from the pedometers, researchers found that using the pedometer to estimate steps per minute resulted in an accurate measurement of physical activity participation in physical education classes. Scruggs (2007) also used direct observation and Yamax Digi-Walker (SW 701) pedometers to assess physical activity in fifth- and sixth-grade physical education classes by comparing SOFIT results to time spent at an established steps per minute threshold over a 30 minute activity period. A similar study used a modified SOFIT instrument and Yamax Digi-Walker (SW 701) to measure the correlation between steps per minute and percent MVPA, and to determine a steps per minute standard to predict 33.33% of a physical education lesson time spent in MVPA (Scruggs et al., 2003). Instead of recording teacher behaviors or instructional focus, the researchers only recorded student activity measurements in three activity categories: sedentary, walking, and very active. They then calculated mean steps per minute by dividing the total step count by total class time.

As hypothesized, researchers found that the mean steps per minute were strongly correlated with percent MVPA in their samples. They also found, based on certain criteria for determining optimal cut points, that mean steps per minute estimates of 60.00, 60.63, and 61.14 steps were the best indicators for 33.33% of lesson time in MVPA. Due to the strong correlation between the step counts and the percent MVPA, the study suggests that these pedometer steps per minute scores would be accurate measurements of time spent in MVPA for physical education classes (Scruggs et al., 2003). This could allow physical educators to evaluate how long their students spend in MVPA, in order to determine whether their program is sufficiently active.

Considerations for Choosing a Pedometer

Due to the variability of personal needs, goals, and physical attributes, it is important for consumers to choose a pedometer that reflects their respective purposes. Melanson et al. (2004) suggested that persons choosing a pedometer should base their purchase on their individual needs and the sensitivity of the pedometer. Certain variables may affect the accuracy of pedometers, which consumers need to consider when they make their choice. Another factor to consider is the cost of pedometers, as opposed to other devices that assess ambulation as physical activity.

One advantage to using a pedometer is that it typically costs much less than other alternatives, like an accelerometer. The average pedometer may cost around 10 to 50 dollars, while the average accelerometer costs between 100 to 500 dollars (Zan et al., 2010). The average consumer does not require an accelerometer in order to measure his or her physical activity levels, and therefore could benefit financially from simply using a pedometer instead of an accelerometer to measure daily physical activity. However, there are certain variances within pedometers that are relative to their cost.

The least expensive pedometers only measure steps. One advantage of the more expensive pedometers is that they generally have more features. For example, they may provide distance converters when users input their stride length, estimation of kilocalorie requirements, and store several days of step count information. This can make it easier to conduct research because pedometers can be sealed, allowing subjects to use them for a week and then return the pedometers to the researchers. This lowers the chance of a subject altering or tampering with the pedometer and changing the settings or recordings. One disadvantage of most pedometers is that they are not waterproof and, therefore, cannot be used for activities in pools or other wet environments.

In summary, pedometers have been a useful physical activity tool in schools, communities, and research settings. They are more cost-effective and accurate since their invention several centuries ago. Pedometers have grown in popularity and in recent years have become a common household item in the United States. While pedometers cannot accurately measure all types of physical activity, most are accurate in recording walking step counts at normal speeds, and are valuable instruments for measuring moderate to vigorous bipedal physical activity. When deciding which pedometer to use, consumers and researchers should consider the factors that may affect accuracy, and choose the right pedometer for their individual needs.

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Appendix B: Tables and Figures

Table 1

Pedometer Types and Accuracy

Company and Model Number	Type of Pedometer	Accuracy	Sources
Yamax, Inc.: Yamax Digi-Walker SW 701	Spring-levered arm pedometer	Accurate in comparison to Actical activity monitor (Mini-Mitter Co., Inc.) for measuring middle school physical activity; significantly accurate at all speeds compared to actual steps; significantly underestimates step counts while skipping, galloping, and sliding	(Crouter et al., 2003; Smith & Schroeder, 2010; Zan et al., 2010)
Yamax, Inc. : Yamax SW-200	Spring-lever pedometer	Reasonably accurate for free-living estimate; significantly undercount at slow speeds; inaccurate for individuals with a high absolute pedometer tilt angle	(Crouter, Schneider, & Bassett, 2005; Duncan et al., 2007; McClain, Hart, Getz, & Tudor-Locke, 2010; Melanson et al., 2004)
Omron Healthcare Inc.: Omron HJ-151	Uniaxial piezoelectric pedometer	Reasonably accurate for free living estimate; comparative accuracy at slow speeds to Actigraph accelerometer	(McClain et al., 2010)
New Lifestyles, Inc.: NL-1000	Uniaxial piezoelectric pedometer	Reasonably accurate for free living estimate; comparative accuracy at slow speeds to Actigraph accelerometer	(McClain et al., 2010)
New Lifestyles, Inc.: NL-800	Piezoelectric pedometer	Accurate in counting steps when walking; significantly underestimates step counts while skipping, galloping, and sliding	(Smith & Schroeder, 2010
Walk4Life, Inc.: W4L Pro	Spring-lever pedometer	Reasonably accurate for free-living estimate; undercount at slow speeds	(McClain et al., 2010)
Yamasa Skeletone: EM-180 (SK)	Piezoelectric pedometer	High accuracy at most speeds	(Crouter et al., 2003)
Sportline: SL330	Spring-lever pedometer	Accurate at most speeds; undercount at slow walking speeds	(Crouter et al., 2003)
Sportline: SL345	Spring-lever pedometer	Accurate at most speeds; undercount at slow walking speeds	(Crouter et al., 2003)
New-Lifestyles: Digiwalker SW-200	Spring-lever pedometer	Significantly accurate in self-selected outdoor speeds or at fast walking speeds, on treadmill underestimated counts at slow speeds	(Grant et al. 2008)
New-Lifestyles: NL-2000	Piezoelectric pedometer	Extremely accurate, with <2% error except in slowest of speeds; undercounts at slow speeds in adults and children; unaffected by pedometer tilt angle	(Crouter, Schneider, & Bassett, 2005; Crouter et al., 2003; Duncan et al., 2007; Grant et al. 2008)
Omron: HF-100	Piezoelectric pedometer	Accurate except with slowest speeds (<1.8 mph)	(Melanson et al., 2004)
Walk-4-Life: LS-2500	Spring-lever pedometer	Very accurate at speeds >3 mph, but significantly undercounted steps at slower speeds	(Melanson et al., 2004)
Step Keeper: HSB-SKM	Spring-lever pedometer	Fairly accurate at speeds >3 mph, but significantly undercounted steps at slower speeds	(Melanson et al., 2004)
Kenz Lifecorder (KZ)	Piezoelectric pedometer	Shows acceptable accuracy in speeds as low as 2 mph	(Crouter et al., 2003)
Walk4Life LS 2525 (WL)	Spring-lever pedometer	Shows acceptable accuracy in speeds as low as 2 mph	(Crouter et al., 2003)

Table 2

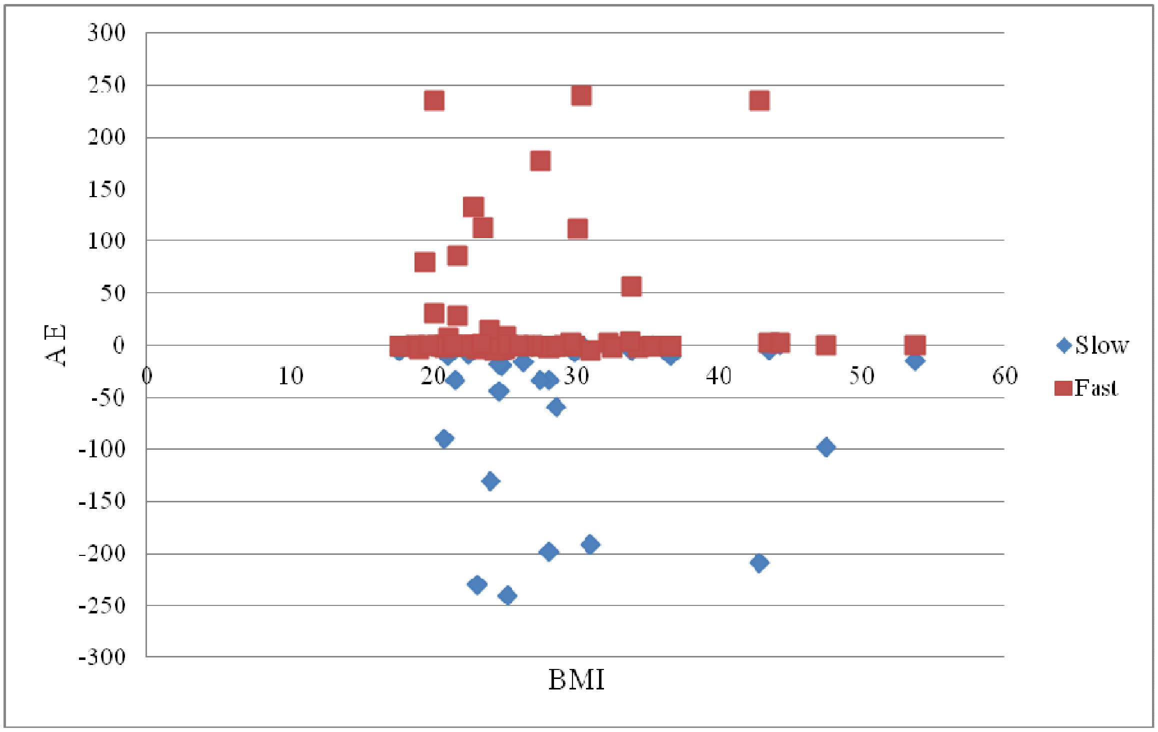
Comparison of Absolute Error (AE) for Slow and Fast Treadmill Speeds

		BMI	Slow	Fast
	N	M (SD)	M (SD)	M (SD)
Men	27	26.97 (7.53)	-31.29 (70.27)	23.62 (61.17)
Women	38	26.52 (7.27)	-23.18 (52.08)	23.18 (59.07)
Both	65	26.70 (7.37)	-26.55 (59.92)	23.53 (59.47)

Notes: AE in number of seconds. Actual means reported and not adjusted for the covariate.

Figure 1

Scatterplot of Absolute Error (AE) against Body Mass Index During Treadmill Tests



Notes: AE = expected minus actual. AE in number of seconds.

Table 3

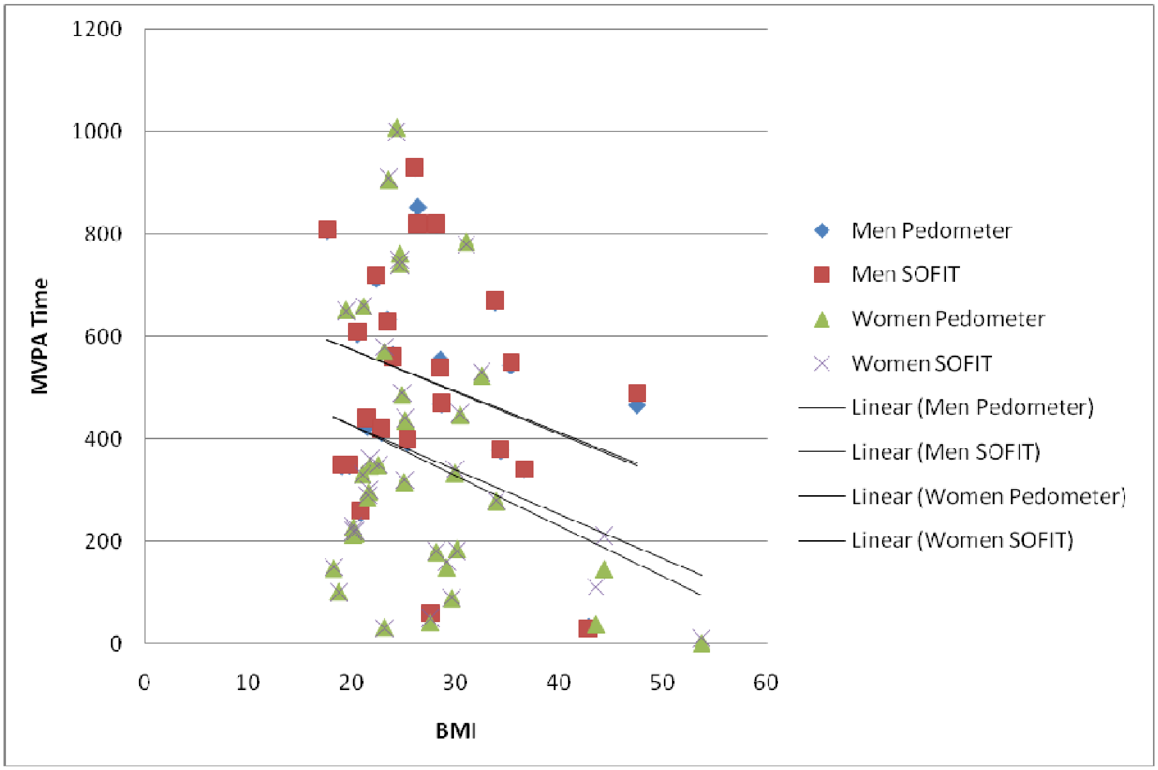
Comparison of MVPA Time by Estimator During Direct Observation

		BMI	Pedometer	SOFIT
	N	M (SD)	M(SD)	M(SD)
Men	24	27.26 (7.63)	513.50 (232.91)	515.42 (230.36)
Women	34	26.70 (7.81)	360.18 (266.43)	367.35 (260.64)
Both	58	26.93 (7.67)	427.62 (262.28)	428.62 (247.20)

Notes: Time in number of seconds. Actual means reported and not adjusted for BMI. Available activity time was 1200 seconds.

Figure 2

Scatterplot of MVPA Time against Body Mass Index for Women and Men During Direct Observation



Note: Time in number of seconds. Available activity time was 1200 seconds.