Pedometry Methods for Assessing Free-Living Adults

Catrine Tudor-Locke, David R. Bassett, Michael F. Shipe, and James J. McClain

Background: The purpose of this review is to update the methodological aspects of pedometry to encourage the consistent use of pedometers for assessment, to decrease sources of error, and to facilitate comparison and interpretation of results. Methods: The specific measurement topics addressed include: instrument choice, metric choice, validity, reliability, data collection and retrieval, time worn, day-to-day variability, monitoring time frame, reactivity, and data treatment. Results: A wide variety of valid and reliable instruments are commercially available and we can expect continued evolutions in value-added features as supporting technology improves. Data collection and retrieval has been achieved through various methods, including face-to-face contact, fax, e-mail, website, and conventional mail, and sometimes a combination of these. Day-to-day variation is not random, as would be expected from inconsistent pedometer performance, but rather exposes true behavior instability that can be explained by other factors and described using a coefficient of variation. Data reduction should be conducted cautiously and only after a full discovery (and disclosure) of its impact on aggregated group statistics and their relationship with other parameters. Conclusions: We have no doubt that research with pedometers will continue to yield new and important insights in the coming years.

Keywords: walking, physical activity, measurement, protocols

Recent technological advances have produced the unique opportunity to objectively assess physical activity using pedometers and accelerometers. Although accelerometers are undeniably important in terms of the study of physical activity intensity and pattern (important components of public health recommendations), pedometers are generally considered more practical for individual and population level applications, due to instrument cost and feasibility of data collection and management. Pedometers provide a simple and affordable means of tracking daily physical activity volume (especially walking) expressed as steps/day. Further, pedometer outputs correlate highly with that of accelerometers.

In 2001, Tudor-Locke and Myers published Methodological Considerations for Researchers and Practitioners Using Pedometers to Measure Physical (Ambulatory) Activity. At that time, we attempted to provide direction useful for planning data collection. Specifically, we focused on choice of metric, monitoring frame, and different recording and collection procedures. Today the field is far more advanced and pedometers (and other types of step counters) are being routinely used for primary outcome assessment or as adjunct measures. Therefore, we believed that it would be useful to update the pedometry methods to encourage their consistent use for assessment purposes, to decrease sources of error, and to facilitate comparison and interpretation of results. Measurement topics have been expanded to include: instrument choice, metric choice, validity, reliability, data collection and retrieval, time worn, day-to-day variability, monitoring time frame, reactivity, and data treatment. Substantial growth of this field precludes an exhaustive review of all pedometer studies and their methods. Based on the authors’ collective experiences and understanding of select relevant literature, we aim to describe issues of particular importance to the practical application of pedometry.

Instrument Choice

Pedometers are generally worn on the belt or waistband, but some are designed to be worn in a pocket, in a shoe, or on an ankle. Pedometers vary in terms of their cost, internal mechanism and sensitivity. For the waist-borne devices, there are 2 basic types of electronic pedometers in use today. The traditional pedometer uses a spring-suspended horizontal lever arm that moves up-and-down with each step. This lever arm has electrical contacts that open and close an electrical circuit with each step, allowing the number of steps to be counted.

A newer class of waist-mounted pedometer contains a piezoelectric accelerometer mechanism that responds to vertical accelerations at the hip. The accelerometer...
records data at frequent intervals, generating a sine wave during walking or running. By counting either the peaks in acceleration or the zero-crossings (where it goes from positive to negative) these accelerometer-based pedometers can determine the number of steps taken. Some instruments assess the amplitude of these peaks to quantify intensity of steps.

Many of the new piezoelectric pedometers have memory storage capacity. In the case of the New Lifestyles NL-1000 ($50) and NL-2000 pedometers ($70), data can be stored in 1-day epochs over 7 days, and recalled by scrolling through the memory function using buttons on the pedometer. The Kenz Lifecorder EX ($245) and the Omron HJ 720ITC ($32) can store 200 days and 42 days of data, respectively, in 1-hour epochs. The Omron pedometer uses 2 single-axis accelerometers to compute vertical acceleration, and it can be worn in a pocket, on a neck chain, or clipped to a belt. Both of these devices allow data to be transferred to the computer via USB cable. They are especially suitable for large clinical trials where researchers need long-term records of verified exercise adherence, and they greatly simplify data management.

The StepWatch 3 ($525 + $1470 for docking station and software) is an example of an ankle-mounted pedometer. Earlier models of this device were called the Step Activity Meter (SAM). This device contains a motion sensor (accelerometer) and uses movement, position, and timing data to count steps. It can store 60 days of data in 1-minute epochs. The Stepwatch allows a researcher to enter the user characteristics (height, stepping rate, walking speed, and leg motion appearance) and it adjusts the monitor’s sensitivity accordingly. It does not display steps on an LCD screen; the data must be downloaded to a computer. Due to this, and the high cost of the device, the Stepwatch is only useful as a research tool.

The Nike+ ($29) is designed to be worn inside specially designed Nike shoes, inside an indentation in the midsole (under the insole). The Nike+ measures the ground contact time, and uses this information to predict speed of locomotion, distance traveled, and energy expenditure. Data are sent by radio waves from the shoe pod to a receiver unit inserted into an Apple iPod nano, where they are displayed and can be stored and later downloaded to a computer. This device is primarily of interest to walkers and runners who want to track their workouts.

**Metric Choice**

Tudor-Locke and Myers\(^3\) previously recommended that pedometer data should be reported as “steps,” since steps are the most direct expression of what the pedometer measures. This still holds true today. In contrast, distance and energy expenditure are derived values estimated after an individual’s stride length and body mass, respectively, are programmed into the pedometer. They involve certain assumptions and are best regarded as indirect estimates of these variables. Simple waist-mounted pedometers capture ambulatory activity, but they (and other types of motion sensors) do not account for the additional energy expended in stair climbing, uphill walking, carrying loads, and arm activities. Pedometers (and other types of motion sensors) cannot be used during swimming and they generally do not record bicycling since the hips do not undergo large vertical accelerations in this activity.

Numerous studies have collected pedometer data on free-living individuals with the same device, similar methods, and reporting units of “steps/day.” It must be acknowledged, however, that the various instruments define and count a “step” somewhat differently. For example, they may count hip accelerations, ground contact time, or foot accelerations. Sensitivity is controlled by the tension of a coiled spring or hair springs, or micro-processors set with internal thresholds. Regardless, the ability to draw comparisons between studies is reasonably good when high quality, research grade pedometers\(^6\) are employed.

While steps remain the cornerstone of pedometer metrics, there are ancillary measures that have been developed in recent years. In an effort to screen out erroneous “steps” from jostling, the Omron HJ-720ITC only records steps taken in bouts of 4 seconds or longer and the Walk4Life MLS 2505 ($21) records steps taken in bouts of 3 seconds or longer. These features may result in an underestimation of daily step counts in individuals who accumulate many short bouts of activity throughout the day. The Omron HJ-720ITC has a function known as “aerobic steps” which refers to continuous steps accumulated at moderate intensity (ie, at least 60 steps/minute), in bouts of 10 minutes or longer.

The Kenz Lifecorder EX (and the New Lifestyles NL-1000 that shares the same internal sensing mechanism) classifies every 4 seconds of activity into one of 11 intensity categories including nonmovement, microactivity (consisting of brief, nonambulatory movements), and ambulatory intensity categories ranging from 1 to 9. These categories roughly translate into energy expenditure, expressed in METs. These intensity ratings are only approximate, and they typically overestimate walking and running while underestimating other lifestyle activities.\(^7\) As with spring-levered pedometers, estimates of non-ambulatory activities (eg, weight training, swimming, cycling) will be compromised.

**Validity**

The validity of electronic pedometers for counting steps has been examined in several studies.\(^4,8–12\) Most often, criterion-referenced validity is determined through comparisons to direct observation of steps taken at various walking speeds. At the start of each trial, the pedometer is reset to 0. After each stage, the number of steps recorded by the pedometer is compared with those directly counted using a hand-tally counter. Validity can be determined from the mean percent error [(criterion—estimate)/criterion × 100%] at each speed. However, since a device
that greatly overestimates 50% of the time and greatly underestimates 50% of the time might appear accurate when it is not, some researchers choose to report the mean of the absolute value of the percent error (APE).\textsuperscript{13}

Table 1 shows a listing of various pedometer models (including costs) that have been validated over the past 10 years. The Yamax SW200 ($18) is one of the most accurate and commonly used spring-levered pedometers in research studies.\textsuperscript{12,13} The Yamax SW-200 has even been used as a criterion against which other pedometers were compared. For instance, Schneider et al\textsuperscript{12} identified the Yamax SW200, Kenz Lifecorder, the New Lifestyles NL-2000, and the Yamax SW-701 ($25) as the most suitable models for research purposes.

The new piezoelectric pedometers (eg, New Lifestyles NL-1000, Kenz Lifecorder, Omron HJ-720ITC) generally have superior accuracy to spring-levered pedometers, especially at slow walking speeds (eg, \(<2mph)\textsuperscript{9,14,15} In addition, piezoelectric pedometers have greater accuracy in obese people. Melanson et al\textsuperscript{14} reported that the accuracy of a spring-levered pedometer (Yamax SW-200) was inversely related to age, weight, and BMI. In the same study, they examined the accuracy of the Omron HJ-105, which they reported was a piezo-electric pedometer, and found it to be greater than that of 2 spring-levered pedometers. (However, we have examined the Omron HJ-105 and found it to be an adjustable tension, spring-levered pedometer.) Crouter et al\textsuperscript{15} compared a spring-levered pedometer (Yamax SW-200) and piezoelectric pedometer (New Lifestyles NL-2000) at speeds between 2.0 and 4.0 mph. They found that the spring-levered pedometer was less accurate in people with a large waist circumference, and on people for whom the pedometer was tilted forward or backward when placed on the belt. In contrast, the NL-2000 was highly accurate across all speeds, for all individuals. The bottom line is that a piezoelectric pedometer is the instrument of choice for research measurement with obese participants. Practitioners focused on motivation may still opt for traditional pedometers, but need to be cognizant of proper attachment, so as to reduce the effect of tilt on measurement error.

The accuracy and reliability of the Omron HJ-720ITC was examined in a recent study by Holbrook et al.\textsuperscript{16} Forty-seven adults (mean age 24 years) were tested under controlled and free-living conditions. In the controlled condition, 34 individuals completed 3 100-m walking trials at slow, moderate, and very brisk paces, while wearing the pedometers in the right pocket, left pocket, and in a backpack. In the free-living setting, 31 individuals completed a 1-mile walk. With the exception of the backpack position in the controlled setting, the Omron HJ-720ITC accurately recorded step counts under controlled and free-living conditions (mean absolute

### Table 1 Various Pedometer Models (Including Costs) That Have Been Validated Over the Past 10 Years

<table>
<thead>
<tr>
<th>Company</th>
<th>Model</th>
<th>Average % of steps recorded (3 mph)</th>
<th>Functions*</th>
<th>Approximate cost</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accusplit</td>
<td>Eagle Digi-walker 2</td>
<td>100</td>
<td>S, D, C</td>
<td>$20</td>
<td></td>
</tr>
<tr>
<td>Kenz Life</td>
<td>Lifecord Plus</td>
<td>100</td>
<td>S, C, 60-day M</td>
<td>$130</td>
<td>9</td>
</tr>
<tr>
<td>Freestyle</td>
<td>Pacer Pro</td>
<td>96</td>
<td>S, D, C</td>
<td>$18</td>
<td>9</td>
</tr>
<tr>
<td>New Lifestyles</td>
<td>NL-2000</td>
<td>100</td>
<td>S, C, 7-day M</td>
<td>$70</td>
<td>9</td>
</tr>
<tr>
<td>Omron HJ-105</td>
<td>HJ-2000</td>
<td>100; MAPE = 8</td>
<td>S, D, C</td>
<td>$18</td>
<td>9</td>
</tr>
<tr>
<td>Omron HJ-112</td>
<td>HJ-700IT</td>
<td>99*</td>
<td>S, D, C</td>
<td>$23</td>
<td>15</td>
</tr>
<tr>
<td>Omron HJ-720</td>
<td>PE316CA</td>
<td>112</td>
<td>S, D, C</td>
<td>$20</td>
<td>9</td>
</tr>
<tr>
<td>Oregon Scientific</td>
<td>PE316CA</td>
<td>112</td>
<td>S, D, C</td>
<td>$20</td>
<td>9</td>
</tr>
<tr>
<td>Sportline</td>
<td>345</td>
<td>MAPE= 33</td>
<td>S, D, C</td>
<td>$26</td>
<td>13</td>
</tr>
<tr>
<td>Sportline</td>
<td>330</td>
<td>93</td>
<td>S</td>
<td>$11</td>
<td>9</td>
</tr>
<tr>
<td>Stepwatch</td>
<td>3</td>
<td>100</td>
<td>S</td>
<td>$ 525 + $1470 for software &amp; docking station</td>
<td>18, 61</td>
</tr>
<tr>
<td>Walk4Life</td>
<td>LS 2525</td>
<td>100</td>
<td>S, D, C</td>
<td>$29</td>
<td>9</td>
</tr>
<tr>
<td>Yamax Skeleto</td>
<td>100</td>
<td>S</td>
<td>$15</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Yamax SW-200</td>
<td>100</td>
<td>S</td>
<td>$18</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Yamax SW-701</td>
<td>100</td>
<td>S, D, C</td>
<td>$25</td>
<td>15, 18</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: S, steps; D, distance; C, calories; M, memory; MAPE, Mean absolute percent error.

* Steps recorded by pedometer worn in pants pocket; value shown is average of steps recorded at 2.5 and 3.5 mph.
percent error, or APE <3.0%). In addition, interdevice reliability was high under both conditions (coefficient of variation <2.1%). The authors concluded that this pedometer has good accuracy and reliability during continuous walking bouts.

The StepWatch is generally considered most appropriate for older individuals who walk with a very slow, shuffling gait and for obese individuals in whom abdominal fat causes inaccuracies for waist-mounted pedometers.17,18 However, the high price and lack of an LCD display limit its feasibility for many applications. The StepWatch 3 records nearly 100% of steps at speeds ranging from 1.0 to 4.0 mph.18 In contrast, the Yamax SW-701 spring-levered pedometer records 38% of steps at 1.0 mph, 86% of steps at 2.0 mph, and 100% of steps at 3.0 and 4.0 mph. However, the importance of counting such low force movements as quality steps may be debated.19 Furthermore, the StepWatch 3 has been shown to record some extra steps during foot tapping, leg swinging, and car driving, although these probably do not contribute a significant amount of error over the course of a 24-hour day.

**Reliability**

Interinstrument reliability of electronic pedometers has been determined by examining the variability between repeated trials of the same activity. For instance, Schneider et al. tested 4 different pedometers of the exact same model over 400 m. The interinstrument reliability (among 4 pedometers of the same model) was computed from Cronbach’s alpha, which is a measure of internal reliability (repeatability). Values ranged from 0.76 to 0.998; the Yamax SW-701 was 0.992. Researchers and practitioners should select pedometers that are known to be reliable (that is, they have low interinstrument variability within the same model).

**Data Collection and Retrieval**

Pedometer data collection typically requires that participants be instructed on how to attach the instrument and record the output. This instruction has been primarily provided by face-to-face contact, although some researchers have successfully mailed out self-monitoring packages following an initial telephone call.20,21 Regardless of the manner of initial instruction, most frequently participants are asked to record daily step count totals, transferring the digitally displayed results directly to a paper calendar22 and/or ultimately to an electronic record (eg, e-mail, website).23 However, some researchers have chosen to direct participants not to reset the pedometer at daily intervals, but to record accumulated values each day worn and then a final total when the monitoring frame is complete.24

A minimal data set for pedometer data collection can be as uncomplicated as a daily record of steps kept on a simple calendar. A straightforward daily pedometer log capable of capturing information such as date, day of the week, day end totals, time of pedometer attachment and removal, and other possibly relevant information (eg, whether working that day or not, whether sick or not, participation in exercise or sport, etc.) has been published20 and can be readily adapted to specific research or practice needs.

Data retrieval has been achieved through various methods, including face-to-face contact, fax,25 e-mail, website,26 and conventional mail,20,27 and sometimes a combination of these.28 Although typically participants are instructed to record and transmit their own data, as detailed above, some studies have used sealed pedometers thus requiring researchers to unseal and record data upon retrieval.27,29 Some have also attempted to adjust accumulated steps for extraneous steps detected during mail retrieval.27 In the future, more researchers may use an on-board memory (ie, scrolling through the instrument’s memory) to record pedometer data without participant input.30

**Time Worn**

Although a number of studies have reported time worn based on individual records of pedometer attachment and removal,31-33 and it certainly allows the researcher another opportunity to assess compliance to protocol, it does not appear to be an absolute requirement. Indeed, it appears that many more studies of free-living physical activity behavior have reported pedometer results without any mention of time worn. The interest in reporting time worn is a reflection of the desire to justify capture of a valid day of physical activity. The implied concern is that physical activity performed when the motion sensor is not attached will be missed. Schmidt et al.34 conducted a systematic evaluation of this issue specific to pedometer time worn using a number of alternative methods for adjusting for wear time. They also examined the relationship between step counts and theoretically-associated biological measures (eg, BMI, waist circumference, and systolic blood pressure) to assess whether any adjustment method improved correlations evident using just the raw data. No manner of adjustment delivered substantially stronger associations. The researchers concluded that any error related to time worn was linked to participants’ activity level when not wearing the pedometer. Specifically, if those people who remove the pedometer earlier also do little physical activity when it is off, then overall error is minimal. Schmidt et al.34 also speculated that adjusting for time worn by reporting step counts as a rate (eg, steps/hour) might lead to overestimates of physical activity in individuals with short wear times if they are not active after they remove the pedometer. It has been previously suggested that persons who are more physically inactive are likely to remove the device early, if they believe that it has nothing more to assess (ie, it is no longer relevant) in their typically sedentary day.35

**Day-to-Day Variability**

Although we address interinstrument reliability of pedometers above, another form of reliability is focused on the reproducibility (or consistency or repeatability or
stability) of pedometer data between monitored days. Conventional test-retest reliability is confirmed if steps/day are consistent from day-to-day. However, in terms of free-living physical activity, variability of pedometer-determined steps taken between days is more likely due to real-life fluctuations in behavior, or intraindividual variability, and not to inconsistent instrument performance.26 Such day-to-day variation is not random, as would be expected from inconsistent pedometer performance, but rather exposes true behavioral instability that can be explained by other factors. For example, studies have consistently reported decreased steps/day on weekends, and specifically on Sundays.37,38 Along the same lines, pedometer-determined physical activity is known to fluctuate by season.28 Variability can also be explained by participation in sport/exercise behaviors,28,39 work,28 and possibly shopping.33 A coefficient of variation (CV) [CV = (SD/mean) × 100] can be used to describe intra-individual variability of steps/day; a study of free-living nursing students indicated that CV calculated over the course of a week of monitoring averaged 35 to 36%.37 Few other studies have reported CV and therefore there is little information to judge its magnitude at this time.

Monitoring Time Frame

Although day-to-day variability appears to be a feature of pedometer-determined free-living physical activity, it is necessary to reduce the variability in pedometer output to achieve a reliable estimate of an individual’s habitual physical activity. It is well known that the number of days assessed increases, within-individual variability decreases.40 However, researchers must also consider minimizing participant burden while using resources efficiently. These considerations have driven the quest for “how many days?” A question in response is “to estimate what, exactly”? Typically, researchers have attempted to determine the minimal number of days necessary to reliably estimate a weekly average. Applying these parameters in healthy adults, combinations of 3 days produce reliable estimates exceeding ICC = .8038 and .90,37 both considered sufficiently reliable. There is evidence to suggest even fewer days may be necessary in populations living with chronic illness, taking fewer steps/day, and therefore less variable in their day-to-day behavior.41 If the minimally acceptable reliability criterion is reduced to an ICC = .70, for example, then even a single day37 may be sufficient for estimating population level behavior, which would be very useful in terms of surveillance efforts. This is further supported by studies that show very little mean difference between most days of a week monitored.33,37,38 However, to achieve a reliable estimate of individual habitual behavior over a longer term (eg, more than a month or more than a year), additional days are required, and there is also an advantage to selecting random vs. consecutive days. Kang et al42 demonstrated that at least 5 consecutive days or 6 random days were necessary to achieve an ICC of .80 when compared against a year-round average of steps/day. A minimum of 30 consecutive days or 14 random days were necessary to achieve a mean APE lower than 10%. In the end, there is no single answer to the question posed. Researchers must carefully consider what they are attempting to estimate (eg, a snap shot of current physical activity or an indicator of habitual, long-term behavior), the characteristics of the target population, the resources at hand, and the tolerance of participants for extended monitoring.

Reactivity

Reactivity occurs when people change their behavior due to awareness that they are being monitored. Since users can typically view the display and observe how many steps they are taking, certain individuals may set out to accumulate more steps, either because they are trying to please the researcher or because they are inherently motivated to achieve a high step count. Some studies have shown an absence of pedometer reactivity,43,44 whereas others have clearly demonstrated evidence of reactivity.45–47 Taken together, these studies suggest that pedometer reactivity may exist under certain conditions. If participants are instructed to wear a pedometer, are allowed to view the display, and are instructed to log their steps, there may be up to a 15% increase in their daily step counts, compared with when they are not aware their steps are being monitored. If they are given a pedometer and allowed to view the display, their step counts are 10% higher than if steps are measured covertly. However, if they are given a sealed pedometer and are not allowed to view the display, there is little or no effect on physical activity. The practical implication of this research is that to obtain accurate baseline data, whenever possible researchers should seal the pedometer and not allow participants to view the display or use an instrument that allows the researcher to block this type of feedback. At the very least, researchers should acknowledge that the results of participant-recorded data may be somewhat inflated. Still, this level of inflation is much less than what has come to be expected of successful pedometer interventions.48,49

Data Treatment

Data treatment includes decision rules applied to improve quality of data by addressing missing values, identifying outliers and reducing data appropriately if necessary, and transforming the data as required in preparation for inferential statistics and/or comparisons between subgroups and/or studies.

Missing Values

The nature of pedometer data collection, requiring days of participant compliance to monitoring protocols, inevitably results in at least some degree of missing data due to pedometer loss, damage, and or participant forgetfulness, inaccurate records, or attrition. Missing data represent lost information and as such are considered a threat to validity since their presence can violate statistical assumptions.
and ultimately reduce power. The best strategy is to plan to prevent missing data as much as possible by a combination of participant incentives, regular contact, continuous checking of participant records for accuracy and completeness, and immediate follow-up contact in the case of questionable or missing data. Some researchers have also asked participants to record if the pedometer is removed for any reason throughout the day (eg, for bathing, showering, or swimming) as a quality control check.24 As mentioned above, some recently available pedometers offer a memory function, capable of storing days of data, relieving the necessity for daily recording (or providing an opportunity for verification of written records). In addition, it may be prudent to further anticipate it by recruiting larger samples and/or more days of data collection. The unfortunate trade-off of this latter suggestion, however, is that the more days that participants are asked to monitor their behavior, the more likely that there will be missing data. Again, there is no straight forward answer to this conundrum; however, awareness of the issues and then vigilance during pedometer data collection is imperative.

Once missing data are identified, then they must be dealt with during data treatment. Deleting participants from the data set is one strategy, but should only be done as a last resort because, as stated before, missing information is undesirable. Alternatively, Kang et al50 have advocated replacing missing data by imputation using an individual-centered approach (vs. an approach that replaces missing data by an aggregated group value). An evaluation of the impact of such an approach has not been reported in adults. However, Rowe et al51 reported that, in children, the process produced an improvement in data reliability with no statistical difference in mean values. The authors also noted no difference in the relationship between pedometer-determined physical activity and leisure time physical activity questions, whether the original data or the replaced data were used. Of course, more complex approaches to dealing with missing data using general statistical techniques (eg, general estimating equations or GEE models) may be more suitable depending on data set and research questions.

**Identifying and Addressing Outliers**

In addition to addressing missing values, data treatment requires that outliers be identified and decisions be made about reducing the data. On any single day, it is plausible for a healthy adult to take <1000 steps/day (eg, on a sick day spent home from work) or >25,000 steps/day (eg, on a day of sight-seeing, or of a special sporting event). However, to average these values over the course of a multiple-day monitoring frame should be considered rare and therefore suspicious. That being said, individuals who are elderly, homebound/institutionalized, and/or living with chronic illness may in fact regularly take <1000 steps/day.52 Regardless, as indicated above, such values (ie, <1000 or >25,000) should immediately trigger follow-up verification during data retrieval. After the fact, such anchors can be used to guide identification, but the impact of reducing data sets by deleting these individual values has not been systematically evaluated. Data reduction should be conducted cautiously and only after a full discovery (and disclosure) of its impact on aggregated group statistics and their relationship with other parameters.

**Data Transformation**

Data transformation may be necessary to address possible errors, to convert data for comparison purposes, to reduce variability in preparation for specific analyses, and to structure the data in standardized strata. Miller et al53 evaluated different methods of accounting for missed nonambulatory activities (eg, swimming, cycling) when using pedometers to assess physical activity. Since non-ambulatory activity accounted for only a small proportion of all physical activity for the majority of participants studied, the authors concluded that transforming data were probably not necessary for population estimates. However, when using pedometers to evaluate change in interventions or for clinical purposes, a conversion factor which considers nonambulatory activities appears to be prudent.53

For comparisons between studies, it may be necessary to convert data. For example, the ActiGraph AM-7164 accelerometer is known to have a lower sensitivity threshold than the Yamax pedometers, leading to relatively higher step estimates.10,11 Tudor-Locke et al53 censored ActiGraph steps taken below 500 activity counts/minute (an indicator of the relatively low intensity of those steps) and produced a reasonable estimate of free-living physical activity congruent with what is expected for Yamax-detected steps/day. Of course, confirmatory research is required before widespread adoption of such a conversion factor. However, current models ($299 for GT3X+) may not need to be treated in this manner. Another example of data conversion is of the ankle-mounted StepWatch. It is worn on 1 leg and detects a “stride,” or “gait cycle,” and the output can be multiplied by 2 (since 1 stride = 2 steps) and presented as steps/day. The Stepwatch is more sensitive than waist-mounted pedometers and it detects nearly 100% of steps, even at a walking speed of 1 mph.18,54,55 However, the Stepwatch is also more likely to record foot-tapping18 and bicycle pedal strokes as steps. At present, it is not entirely clear how data from the Stepwatch should be converted to yield data comparable to waist-mounted pedometers.

Another form of data conversion is translating pedometer-determined steps taken to estimates of time spent in moderate-to-vigorous intensity physical activity, another important component of public health recommendations.1 A threshold value of ~100 steps/minute has been suggested for detecting activities at or above 3 METs within young healthy adult populations.56 Using this conversion factor, researchers and practitioners are able to interpret intervention change measured in steps in terms of equivalent time spent walking.
In 2004, Tudor-Locke and Bassett, Jr.\textsuperscript{57} established preliminary pedometer-determined physical activity cut points for healthy adults: 1) <5000 steps/day (sedentary); 2) 5000 to 7499 steps/day (low active); 3) 7500 to 9999 (somewhat active); 4) 10,000 to 12,499 (active); and 5) ≥12,500 steps/day (highly active). These step categories were reinforced in 2008.\textsuperscript{58} Transforming raw pedometer data into these categories and reporting proportions in cut points) in preparation for further analyses and/or to insights in the coming years. Due to advances in our understanding, research may be replaced using the procedures reviewed in this collection and retrieval. Thoughtful treatment of data, improvements in accuracy and reliability. Researchers technology (eg, piezo-electric mechanisms) have led to burden, ease of use, and having an output (ie, steps) that monitoring devices including low cost, low participant issues surrounding the pattern and intensity of activity, physical activity. While not ideally suited for assessing now accepted research tools for measuring ambulatory come a long way in the past decade. Pedometers are In conclusion, the field of pedometer research has pedometer-determined steps/day exist\textsuperscript{60} and these can be yet been evaluated. Finally, BMI-referenced cut points for although the integrity of these lower categories has not 12,500 steps/day (highly active). These step categories were reinforced in 2008.\textsuperscript{58} Transforming raw pedometer 1) 7500 to 9999 steps/day (indicative of basal physical activity) and 2,500 to <2500 steps/day (somewhat active); 2) 5000 to 7499 steps/day (low active); 3) 7500 to 9999 steps/day (indicative of limited physical activity).\textsuperscript{35} although the integrity of these lower categories has not yet been evaluated. Finally, BMI-referenced cut points for pedometer-determined steps/day exist\textsuperscript{60} and these can be used to stratify samples dichotomously (above or below cut points) in preparation for further analyses and/or to compare data between subgroups and/or studies. Summary and Conclusions In conclusion, the field of pedometer research has come a long way in the past decade. Pedometers are now accepted research tools for measuring ambulatory physical activity. While not ideally suited for assessing issues surrounding the pattern and intensity of activity, pedometers have several advantages over other objective monitoring devices including low cost, low participant burden, ease of use, and having an output (ie, steps) that is implicitly understood. Recent advances in pedometer technology (eg, piezo-electric mechanisms) have led to improvements in accuracy and reliability. Researchers should be aware of standard protocols for pedometer data collection and retrieval. Thoughtful treatment of data, including rational yet conservative data reduction strategies is necessary. A small percentage of missing days may be replaced using the procedures reviewed in this article. Due to advances in our understanding, research with pedometers will continue to yield new and important insights in the coming years. References


