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Motion Sensor Use for Physical Activity Data: Methodological Considerations

Margaret McCarthy, PhD, RN, FNP-BC and
Yale University School of Nursing

Margaret Grey, DrPH, RN, FAAN
Yale University School of Nursing

Abstract

Background—Physical inactivity continues to be a major risk factor for cardiovascular disease, and only one half of adults in the United States meet physical activity (PA) goals. PA data are often collected for surveillance or for measuring change after an intervention. One of the challenges in PA research is quantifying exactly how much and what type of PA is taking place—especially because self-report instruments have inconsistent validity.

Objective—The purpose is to review the elements to consider when collecting PA data via motion sensors, including the difference between PA and exercise; type of data to collect; choosing the device; length of time to monitor PA; instructions to the participants; and interpretation of the data.

Methods—The current literature on motion sensor research was reviewed and synthesized to summarize relevant considerations when using a motion sensor to collect PA data.

Results—Exercise is a division of PA that is structured, planned, and repetitive. Pedometer data includes steps taken, and calculated distance and energy expenditure. Accelerometer data includes activity counts and intensity. The device chosen depends on desired data, cost, validity, and ease of use. Reactivity to the device may influence the duration of data collection. Instructions to participants may vary depending on purpose of the study. Experts suggest pedometer data be reported as steps—since that is the direct output—and distance traveled and energy expenditure are estimated values. Accelerometer count data may be analyzed to provide information on time spent in moderate or vigorous activity.

Discussion—Thoughtful decision making about PA data collection using motion sensor devices is needed to advance nursing science.

Keywords

accelerometer; pedometer; physical activity

Corresponding Author: Margaret McCarthy, Post Doctoral Fellow, Yale School of Nursing, 400 West Campus Drive, Orange, CT 06516 (margaret.mccarthy@yale.edu).
Margaret McCarthy, PhD, RN, FNP-BC, is Post Doctoral Fellow, Yale University School of Nursing.
Margaret Grey, DrPH, RN, FAAN, is Dean & Annie Goodrich Professor, Yale University School of Nursing.

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Physical inactivity continues to be a major risk factor for cardiovascular disease (Go et al., 2014) that, along with stroke and related vascular deaths, are the leading causes of death in the United States (Lloyd-Jones et al., 2010). Participating in physical activity (PA) at goal levels has been identified as one of the seven core components of ideal cardiovascular health, along with other health behaviors and health factors (Lloyd-Jones et al., 2010). The American Heart Association (AHA) has recommended that adults > 20 years old participate in ≥ 150 minutes of moderate intensity PA per week or ≥ 75 minutes of vigorous PA per week, or a combination of the two (Lloyd-Jones et al., 2010). Unfortunately, only half of adults in the United States meet that goal (Go et al., 2014).

PA data may be collected as surveillance data or to measure change after an intervention. The former often includes occupational, leisure, household, and transportation-related activities (Clemes, Hamilton, & Lindley, 2008). If part of an intervention, baseline and follow-up measures are collected. Additionally, there is an expanding interest in self-tracking one's own behavior, including not only PA, but sleep, diet, and work (Kim, 2014). The Quantified Self movement (Quantified Self, 2012) is a new and expanding practice of self-monitoring, and is one example of the consumer's growing interest in collecting data to manage their own health. Potential participants may already be accustomed to being monitored.

One of the challenges in PA research is quantifying exactly how much and what type of PA is taking place. PA questionnaires that rely on self-report have had mixed results in validation studies, with some studies reporting strong correlations between self-reported PA and objective measures for vigorous-intensity PA (Strath, Bassett, & Swartz, 2004), and others showing self-reported vigorous PA was overreported as compared to accelerometer data (Mäder, Martin, Schutz, & Marti, 2006). Maintaining a diary may provide extensive detail about PA performed, but places a burden on the participant to maintain the record each day (Ainsworth, Cahalin, Buman, & Ross, 2015).

Several options are available for collecting objective data, including physiological measures (heart rate monitors) and motion sensor devices (accelerometers and pedometers) (Strath et al., 2013). Multisensor system devices combine accelerometry with heart rate and respiratory monitoring with multiple physiologic and mechanical sensors (Ainsworth et al., 2015). While all of these approaches are feasible and practical methods of collecting PA data, there are important considerations involved in the selection of the appropriate one. While heart rate monitors may provide time spent in different intensity levels of PA, the data collected may be inaccurate related to other factors that affect heart rate, such as body temperature or emotional stress. Multisensor devices may have high precision, but cost and complexity may prohibit their use (Ainsworth et al., 2015). Accelerometers or pedometers can provide information on frequency, duration, and intensity of PA in a given time period, and their use has increased considerably in recent years (Strath et al., 2013). Thus, the purpose of this paper is to review the elements to consider when collecting PA data in adults via motion sensors, including a review of the following: (a) the difference between PA and exercise; (b) the type of data that can be collected; (c) the choice of the device; (d) the length of time to collect data; (e) the instructions to be given to the participant; and, (f) how to interpret the data once collected.

Physical Activity and Exercise

Although these two terms have been used interchangeably in the literature, PA has been defined as any bodily movement that results in an increased energy expenditure above resting levels, while exercise is a division of PA that is structured, planned, and repetitive with the purpose of increasing fitness (Conn, Hafdahl, Brown, & Brown, 2008). For example, gardening, housework, or shopping might be considered PA, but given their sporadic and unstructured nature, they are not necessarily exercise.

Exercise can be described by four characteristics: type of activity (walking, biking); frequency of activity (number of sessions per day or sessions per week); duration (length of time of each activity session); and intensity (how much energy is spent) (Strath et al., 2013). Metabolic equivalents (METS) are a unit often used to describe the intensity of an activity; one MET is the equivalent of sitting quietly at rest (Strath et al., 2013). Three categories of activity have been described in terms of intensity and amount of METS: light (1.6–2.9 METS), moderate (3.0–5.9 METS), and vigorous (≥ 6.0 METS) (Strath et al., 2013). Examples would include casual walking (light), brisk walking (moderate), and jogging (vigorous) (Haskell et al., 2007). It is important to be able to quantify the intensity of the activity to assess whether current recommendations are being met.

Type of Data to Collect

Pedometers measure the total number of steps taken, and may also provide a calculated distance and energy expenditure (Corder, Brage, & Ekelund, 2007). The raw output data from accelerometers are counts, and these counts can be analyzed and averaged over a certain time frame or epoch to reflect the intensity of exercise (Chen & Bassett, 2005). The length of the epoch can affect interpretation of the data. A shorter epoch may be better if PA is conducted in short sessions, but those short time periods of activity (10–30 seconds) may have little physiological benefit. A longer epoch has the advantage of averaging the activity, but if two different types of activity occur within that epoch, it may lead to misclassification of the type of activity. For most researchers, one-minute epochs of time can be a good option (Chen & Bassett, 2005).

Choosing the Device

The type of data that is required, reliability, validity, ease of use, and cost will influence what device to choose. Currently, the range of devices available is wide—from the simplest pedometer to complex multisensor devices—and there is no one standard wearable monitor (Ainsworth et al., 2015). Pedometers and most accelerometers are uniaxial and sensitive to movement in the vertical plane, while some accelerometers are sensitive to the anteroposterior and lateral planes, making them biaxial or triaxial (Corder et al., 2007). Pedometers and accelerometers have the advantage of being relatively precise, minimally invasive, and providing data in a clear metric (steps).

In nursing research, reliability refers to the consistency of an instrument, while validity is the ability of the instrument to measure what it is intended to measure (LoBiondo-Wood & Haber, 2006). The same confidence in a motion sensor device is both expected and required.

Evidence of reliability has been documented by comparing multiple devices worn simultaneously with minimal variation between devices across different walking speeds (Holbrook, Barreira, & Kang, 2009). Devices may be validated in a controlled setting—by comparing device's step count to a manual count of steps—or in a free-living setting—by comparing step counts of several different models against a criterion device (Lee, Williams, Brown, & Laurson, 2014).

In addition to pedometers and accelerometers that have been used in research in the past, some newer devices have recently been made available, including Fitbit One, Fitbit Tracker, and Fitbit Ultra (Fitbit Inc., San Francisco, CA.). They have demonstrated good reliability and validity for step counts (Noah, Spierer, Gu, & Bronner, 2013; Takacs et al., 2014), but poor validity when estimating energy expenditure (Fitbit Tracker and Fitbit Ultra) (Noah et al., 2013) and distance output (Fitbit One) (Takacs et al., 2014). In a review published in 2014 on the validity of eight commercially available devices (J. M. Lee, Kim, & Welk, 2014), the authors calculated the estimated energy expenditure of each device, including the BodyMedia FIT (arm band), Fitbit Zip, Fitbit One, Jawbone Up (all worn on waist) and the Nike Fuel Band (worn on wrist), which were then compared to actual energy expenditure as measured by indirect calorimetry. The strongest correlations with indirect calorimetry were seen in the BodyMedia FIT (r = .84), the Fitbit One (r = .81), and Fitbit Zip (r = .81). There is a continual need for validating newer devices that are being developed (J. A. Lee et al., 2014), which allows researchers to make informed decisions when designing their research (J. M. Lee et al., 2014).

The ease of use for the participants and researchers, including how the device will be delivered and collected, needs to be considered. If instructions are simple, and the participant reliable, the device may be mailed with instructions on how to initialize and use the device, and how to return it when the monitoring is complete. Face-to-face meetings may be needed in some populations. Many of the newer activity monitors—for example, the Fitbit One—sync to a computer wirelessly (Takacs et al., 2014) providing real-time data.

Lastly, cost is also a factor in the choice of a device. A review of various models that have been validated in the recent past have ranged in price from $11 to $525 (Tudor-Locke, Bassett, Shipe, & McClain, 2011). Actigraph accelerometers have been used for data collection in the National Health and Nutrition Examination (NHANE) surveys and are the most commonly used device in research studies (Bassett, Troiano, McClain, & Wolff, 2014). One current model, the Actigraph wGT3X-BT, currently sells for $225 (ActiGraph, 2014). Costs of devices may vary, if bought separately, as compared to bulk orders. A summary of some currently available devices, along with their features and references for more information, can be found in Table 1.

Length of Time for Data Collection

Usual activity

Typically, researchers are interested in usual activity and may choose to monitor over several days and compute an average. However, the length of time needed to collect reliable data depends on the variability within an individual's daily activity. If a person's activity is fairly consistent, fewer days may be needed to collect usual activity (Corson, Gerrity, & Dobscha, 2004).

Reactivity

Another consideration in determining duration of data collection is the phenomenon of reactivity, which occurs when people change their behavior when they know they are being monitored (Chow, Foster, Gonzalez, & McIver, 2012). Although there is mixed evidence on the presence of reactivity, studies suggest that it may be present in certain conditions. Viewing daily step counts and logging them in a diary may result in as much as 15% higher step counts as compared to being unaware they were being monitored (Chow et al., 2012). In this case, reactivity may last for about one week and, without an intervention, activity would return to normal levels during week two (Clemes & Deans, 2012). To minimize the effect of reactivity, a researcher may use a sealed pedometer where step counts may not be viewed, or ask the participant to wear the device for two weeks, but use only the second week of data.

Recording duration of measurement

The duration of time the participant wears the device each day may be obtained by having the participant record the time of pedometer attachment and removal. Although this allows the researcher an opportunity to assess adherence to the data collection protocol, it is not always required (Tudor-Locke et al., 2011). However, the data on actual time worn have the additional benefit of confirming the concept of a valid day, which has been defined as wearing the device for 10 hours in a 24-hour period (Tudor-Locke, Johnson, & Katzmarzyk, 2009).

Longitudinal data

There are two additional considerations related to collecting longitudinal PA data. The first is the need to integrate a theoretical model of behavior change that is consistent with both the temporal design of the research (how often PA observations are measured), as well as the statistical model of analysis (Collins, 2006). Secondly, current motion sensor devices will provide an exhaustive amount of data on the various patterns of PA over time. These changes may be explained by the underlying theoretical model and be understood in the context of dynamical systems modeling, where several inputs (for example, the theoretical constructs of the Health Belief Model) affect the output (behavior change) (Riley, Martin, & Rivera, 2014).

Instructions for the Participant

Participants need to be instructed on how to wear the device, how long to wear it each day, how many days to wear it, and whether they are to record any data during the observation period. Most single monitors should be placed at the waist, even though upper body movement (with lower energy expenditures) will not be captured (Engel, 1977). However, some devices, like the Nike+Fuel Band, are designed to be worn on the wrist (J. M. Lee et al., 2014). If total daily activity is to be collected, participants should put on the device in the morning, and wear it all day until bedtime—removing it only for water-based activities.

Interpreting the Data

Raw data

The basic output from pedometers and accelerometers are step counts and activity counts, respectively. Researchers have recommended that pedometer data should be reported as steps—since that is a pedometer's direct output—and distance traveled and energy expenditure are estimated values after accounting for stride length and body mass (Tudor-Locke & Myers, 2001). Current research conducted in this field promotes the idea of using total activity counts per day as a common metric that will standardize PA across studies (Bassett et al., 2014). Total activity counts, averaged over several days, would represent total daily PA and include all intensities of exercise. The authors suggest counts could be converted to age and gender-specific percentiles—based on population data—allowing a comparison to others of the same age and gender.

Data processing

Accelerometer step count data may be analyzed to provide information on the amount of time spent in activities of different intensity. To calculate intensity, thresholds have been determined for both moderate intensity (threshold of 2020 counts/minute)—equivalent to 3 METS—and vigorous intensity (threshold of 5999 counts/minute)—equivalent to 6 METS (Troiano et al., 2008).

Energy expenditure values are estimated from data obtained from the motion sensor. However, poor predictive validity has been reported in estimating energy expenditure which, may be a result of limitations in the monitors, or in the lack of population-specific regression equations (Welk, Blair, Wood, Jones, & Thompson, 2000). Many devices are more accurate at estimating energy expenditure at light to moderate intensities, but tend to underestimate at very light or higher intensity activities (Aparicio-Ugarriza et al., 2015). More recently, researchers using nonlinear modeling approaches demonstrated high correlations between estimated energy expenditure using the ActiGraph accelerometer and measured energy expenditures (Montoye, Mudd, Biswas, & Pfeiffer, 2014). Motion sensor devices may be more accurate in estimating physical activity energy expenditure than self-report instruments, but absolute estimates are not accurate (Colbert, Matthews, Havighurst, Kim, & Schoeller, 2011).

Time spent in moderate to vigorous PA has been used to predict the required number of steps per day to achieve a physical activity goal. Tudor-Locke et al. (2011) employed statistical models to analyze NHANE accelerometer data and found 30 minutes per day of moderate to vigorous PA translated into 7900 steps/day for men and 8300 steps/day for women. To achieve 150 minutes of moderate to vigorous PA per week, the researchers calculated 48,582 steps/week for men and 49,415 steps/week for women would be needed.

Total step counts per day can be categorized to establish different levels of activity. These categories are:

- < 5000 steps (sedentary)
- 5000–7499 steps (low active)

- 7500–9999 steps (somewhat active)
- ≥ 10,000–12,499 steps (active)
- ≥ 12,500 steps (highly active) (Tudor-Locke, Hatano, Pangrazi, & Kang, 2008).

Missing data

Data from pedometer- and accelerometer-based studies are missing when participants do not wear the device as instructed. Nonadherence creates downward bias in estimates of activity count data (Catellier et al., 2005). An individual information-centered approach replaces missing values with the mean of the participant's remaining nonmissing days, using the mean of only weekdays or only weekends if there is a significant difference between the two (Kang, Hart, & Kim, 2012); the authors found this method can be safely used to impute two days out of seven. Because mean replacement tends to overestimate true variance in the entire dataset (Staudenmayer, Zhu, & Catellier, 2012), standard statistical approaches to missing data imputation (Little & Rubin, 2002) should be considered.

Discussion

In this review, we have discussed several elements to consider when using any type of motion sensor device to collect PA data. Seemingly every day, newer devices are becoming commercially available, and it remains the researcher's responsibility to select a device that both meets their needs and has established reliability and validity. As with collecting PA data via self-report, there are some limitations in using these devices. Sensors may not compensate for the extra effort of climbing stairs or walking uphill, nor do they account for arm activity if they are worn on the waist. They cannot be used during swimming and may not record activity counts when bicycling (Chow et al., 2012). When pedometers or accelerometers are worn on the waist by the overweight or obese, the device may be placed at an angle, which will limit accuracy due to measuring only in the vertical direction, although this is less of an issue with triaxial accelerometers (Engel, 1977).

The emergence of these newer devices parallels the desire of self-tracking behavior to promote health (Kim, 2014). These devices may serve as motivational tools, especially when combined with recording the activity (or wirelessly syncing the data to a computer) and goal setting (Bravata et al., 2007). Awareness of the potential effect of the devices on behavior may guide decision making about methods of data collection.

Although all of the factors discussed will need to be considered when choosing a device—some may be more favorable depending on the aims of the research. Collecting data on a large sample, for example, may lead one to choose a simple pedometer, but if categorizing intensity of activity is needed, an accelerometer that provides counts per minute may be used. A focus on weight loss may warrant a newer device that tracks calories burned, while a PA intervention may necessitate a device that serves as a motivational tool, as well as a tracking device. Wireless syncing of subject data to a computer may assist researchers in remote data collection. The need for more complex data may be obtained by the use of a multisensor device, although it may place a higher burden on the participant.

An important consideration in choosing an ideal tool for PA data collection is selecting one that will decrease the possibility of measurement error in the chosen sample. To achieve that goal, population characteristics of a potential sample, such as age, gender, race, functional ability, and cognition, should also be taken into consideration (Ainsworth et al., 2015). These characteristics will vary among samples, and their consideration should lead to a tool that is the best match for the aims of the research.

Conclusion

Given the known limitations in collecting self-report PA data, nurses will benefit from making the most informed decision possible about the use of motion sensor devices in collecting PA data. There is a growing body of research available to assist in all aspects of the study design, including the selection of a motion sensor device. Although the process may be a challenge—especially given the expansive numbers of products now available—the advantages will include the collection of more objective and unbiased data.

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TABLE 1

Common Features of Current Motion Sensor Devices

Device	Type	Location worn	Features
Actigraph GT3X[a]	Triaxial accelerometer	Hip	• Wireless sync to computer • 24-hr activity and sleep measurements • Provides energy expenditure, MET rates, steps taken and physical activity intensity • Used to collect physical activity data in the 2013–2014 National Health and Nutrition • Examination Survey (NHANES) • Weak to moderate ICC with manual counting of steps at slower treadmill speeds (3.2–4.8 km/hr); strong ICC with higher treadmill speeds (5.6 and 6.4 km/hr) • In free-living conditions ICC = 0.90 with steps from criterion device
BodyMedia FIT[b]	Three-dimensional accelerometer	Armband	• Tracks activity and calories burned • Data downloaded with USB cable • Designed to facilitate weight control • Strong correlation with indirect calorimetry, a measure of oxygen consumption (r = .84)
Fitbit One [a]	Triaxial accelerometer	Waist	• Measure steps taken, floors climbed, distance traveled, calories burned and sleep quality • Wireless sync to computer • Internal memory that can store data for up to 23 days • Strong correlation with indirect calorimetry (r = .81)
Fitbit Zip[a]	Triaxial accelerometer	Waist	• Measure steps taken, distance traveled, and calories burned • Smaller than Fitbit One and slightly less expensive • Wireless sync to computer • Strong correlation with indirect calorimetry (r = .81)
Jawbone Up[b]	Three-dimensional accelerometer	Wrist	• Monitors sleep and physical activity patterns • Wireless sync to computer • High correlation with indirect calorimetry (r = .74)
New Lifestyles 2000i[c]	Triaxial Accelerometer	Hip	• Provides steps, active minutes, distance and total calories • 7 or 14-day memory • No capability to download data

Device	Type	Location worn	Features
			• Moderate correlation (r = .53) with physical activity energy expenditure (indirect calorimetry)
Nike+Fuel Band[b]	Three-dimensional accelerometer	Wrist	• Data synchronized to Nike website via clasp/USB or wireless pairing to smartphone • Hourly reminders to stay active • Ability to track intensity of workouts • Low correlation with indirect calorimetry (r = .35)
Omron HJ-720[a]	Biaxial pedometer	Hip or pocket	• Measures steps, aerobic steps and minutes, calories and distance • Separate display for aerobic steps and minutes walked > 10 minutes continuously • Seven-day history • Can be purchased with Omron health monitoring system software • Strong ICC with manual counts of steps during all speeds of treadmill walking • In free-living conditions ICC = 0.89 with criterion device's steps
Yamax Digiwalker SW-701[a]	Pendulum-based pedometer	Hip	• Provides steps, distance, stride and calories • Approximately three-year battery life • No capability to download data • Did not differ significantly from manual step counts at all treadmill speeds tested

Note. ICC = intraclass correlation coefficient.

[a]J. A. Lee, Williams, Brown, & Laurson, 2014;

[b]J. M. Lee, Kim, & Welk, 2014;

[c]Colbert, Matthews, Havighurst, Kim, & Schoeller, 2011