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Determining activity monitor wear time: an influential decision rule

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Abstract

Background—Accurately measuring physical activity (PA) with activity monitors requires sufficient monitor wear time which can be difficult to assess. Monitor sensitivity to movement and population characteristics, e.g., children vs. adults, may dictate the duration of monitor inactivity indicative of nonwear. A standardized method for determining appropriate decision rules to identify wear time is needed.

Methods—Several decision rules based on minimum durations of monitor inactivity (i.e. 60, 90, 120, 150 minutes) to identify nonwear were applied to Stepwatch™ Activity Monitor data from 1064 adult bariatric surgical candidates. The frequency, pattern, and duration of resulting nonwear and wear periods were examined. Generalized Estimating Equations tested the effect of these decision rules on PA measures.

Results—A 60 minute duration resulted in unreasonably large percentages of subjects with unlikely wear patterns (e.g. three nonwear periods in a day (29.9%); two wear periods of less than an hour in a day (28.7%)); 120 minutes appeared most reasonable. Wear time decision rules impacted PA measures.

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Conclusions—The methods described in this paper can be used to determine appropriate instrument and population specific wear time decision rules. Recognizing monitor wear time is estimated, PA measures least affected by wear time are preferable.

Keywords

assessment; accelerometer; objective; steps; obesity

INTRODUCTION

With the prevalence of obesity reaching epidemic proportions in the United States and abroad (1), developing effective interventions to prevent and treat obesity is a high public health priority. Epidemiological research provides substantial evidence that physical inactivity is a risk factor for obesity, and conversely, that regularly participating in moderate or vigorous intensity physical activity (PA) helps people achieve and maintain a healthy body weight (2;3). Recent reports suggest that PA is also an important component of weight loss following bariatric surgery (4;5), the most effective and durable treatment for severe obesity (6).

To improve understanding of how PA relates to weight loss and weight maintenance, accurately assessing free-living PA is critical. Thus, more researchers are turning to accelerometers and step activity monitors for an objective assessment of PA. These activity monitors are small, electronic devices, usually worn on the hip, ankle, or arm, which continuously measure body movement in terms of acceleration, as counts, or steps per epoch length (i.e., unit of time). Thus, they can be used to quantify several dimensions of PA (e.g., total PA, time spent active vs. inactive; duration and frequency of PA at specific intensities) which are important to understanding how PA impacts health (7).

While activity monitors are not subject to some of the biases associated with PA surveys such as over reporting “good” practices or differentiation in ability to recall PA behavior (8), assessing PA with activity monitors has its own challenges. Because monitors only measure PA when worn and a minimum amount of wear time is required to validly assess PA, studies of PA using monitors are dependent on subject compliance for extended periods of time. Subjects are typically instructed to wear the monitor during waking hours or continuously for a set number of days. However, despite efforts to maximize adherence subjects do periodically remove the monitor (from this point forward referred to as nonwear) for various reasons (e.g., appearance, comfort, sporting regulations, bathing, sleeping) after which they may or may not remember to immediately put the monitor back on. Thus, wear time must be identified to determine whether the monitor was worn long enough to provide a valid estimate of PA. Wear time is also used to calculate several commonly used PA measures such as steps per minute.

Several researchers have sought to determine the minimum number of hours per day, and number and type of days that are sufficient to accurately assess habitual PA (9–11). Researchers have also explored how data imputation can be used to minimize wear time requirements (12–14). However, determining nonwear and thus wear time, which should precede determination of wear time requirements, has not been adequately addressed.

Methods to identify nonwear include self-report and examining monitor data for bouts with no recorded activity indicative of nonwear. Disadvantages of the first method include missing data and errors in self-report, which have been demonstrated by lack of agreement between self-report via diary and monitor data (12;14). However, the second approach has disadvantages as well since lack of recorded activity can result from actual inactivity or

from nonwear. Without knowing when the monitor is actually removed, one must make the assumption that lack of recorded activity for some prolonged duration is more likely to be nonwear than actual inactivity. If the selected duration of inactivity used to identify nonwear is too short, actual inactivity will be misclassified as nonwear. If the selected duration is too long, actual nonwear will be misclassified as inactivity. Despite the risk of misclassification, studies reporting minimum durations of inactivity to identify nonwear have not clearly described a method for selecting an appropriate minimum duration (12–29).

This report describes a methodology for examining activity monitor data to identify nonwear, and demonstrates how this methodology is used to establish a wear time decision rule (i.e. data processing rule to identify wear time) in a study of obese adults awaiting bariatric surgery. In addition, four monitor-based and one diary-based wear time decision rules are applied to a dataset to assess the impact of the rules on the percentage of subjects that meet wear time requirements, wear time estimates and several PA measures.

METHODS

Data source

Data were collected as part of the Longitudinal Assessment of Bariatric Surgery-2 (LABS-2), which follows patients at least 18 years old undergoing their first bariatric surgery by participating surgeons at six sites throughout the United States. A comprehensive description of LABS-2 has been previously reported (30). Briefly, LABS-2 is a prospective, observational study designed to comprehensively evaluate patient characteristics as they relate to long-term safety and efficacy of bariatric surgery. Recruitment began in February, 2006 and ended in February, 2009. Data from 1080 LABS-2 subjects who completed a pre-surgical PA assessment before August 15, 2008 were initially examined for inclusion in this analysis. The LABS-2 protocol was approved by the Institutional Review Board at each institution. Prior to participation, subjects provided written informed consent.

Physical activity assessment

The StepWatch™ 3 Activity Monitor (SAM) (OrthoCare Innovations, Washington, D.C.) was used to measure PA. The SAM is a waterproof microprocessor-controlled biaxial PA monitor that combines acceleration, position, and timing information to count steps taken every minute. It is designed to capture step-based ambulation, which accounts for the majority of PA energy expenditure (31), and provides steps, a unit of measurement that is easily interpretable. Because the monitor is worn just above the ankle it is not susceptible to motion of soft tissue which can induce significant errors in belt worn devices. Also, because of directional sensitivity, the SAM is not affected by off-axis accelerations and will not pick up vehicle vibration and similar events that may be counted by other monitors. Numerous studies have shown that it is accurate in lean and obese individuals at “slow” (1 mph) and “purposeful” (2–3 mph) walking speeds and with a variety of gait styles, with accuracy typically exceeding 98% (32).

Study staff at each site were trained and certified before PA assessment began. During the pre-surgical research visit, the monitor was programmed with sensitivity settings appropriate to the subject’s height, cadence, and gait speed using accompanying software (32) and set to immediately record data. To ensure technical reliability of the SAM and appropriateness of settings, a verification light on the monitor was set to flash for the first 100 steps; study staff confirmed that the monitor blinked one time per step while observing subjects walk at their normal pace as well as their slowest and fastest paces. To maximize compliance, subjects were encouraged to wear the monitor continuously, for seven consecutive days following their clinic visit or until the day of surgery. However, assuming that not all subjects would

find night-wear tolerable, subjects were instructed that they could wear the monitor during waking hours only. Based on other researchers' experience (1, 26) we felt that assessing wear time from self-report of exact wearing practices would result in poor quality data. However, in order to prompt subjects to make-up an assessment day for days in which monitor wear time might be insufficient, the PA diary included the question: "How many hours were you awake today, but not wearing the SAM? This includes the time between when you got out of bed in the morning and put on your SAM, the time between when you took off the SAM and got into bed, and the time that you removed the monitor during the day." Choices were less than an hour, 1–<3 hours, 3–<5 hours, and 5 or more hours. On days subjects selected "5 or more hours" the PA diary prompted them to wear the monitor for an additional day. However, 327 (30.0%) received the monitor three to eight days before surgery so they could not make-up an assessment day. Subjects did not record whether they chose to wear the monitor continuously.

LABS-2 subjects were excluded from PA if their clinic visit was within three days of their scheduled surgery, they exclusively used a wheelchair, they had a health-related reason other than obesity that limited walking (e.g. multiple sclerosis), a temporary injury that affected walking (e.g. sprained ankle), or a medical condition that could be exacerbated by wearing the monitor (e.g. edema), or no monitors were available for distribution.

Determining a wear time decision rule

While subjects were given the option of wearing the monitor continuously, only wear time during waking hours was of interest. Thus, we needed to determine a length of inactivity likely to distinguish awake wear periods from sleep and nonwear. Because subjects were unlikely to remove the monitor multiple times per day on a regular basis (23), they should have zero or one nonwear period per day on most days. Furthermore, because subjects were unlikely to regularly wear the monitor for brief periods of time, wear periods of, for example, less than an hour should be rare. We used these assumptions to evaluate various minimum durations of inactivity to identify sleep and nonwear. Specifically, we examined the frequency and distribution of nonwear periods and the duration of wear periods that resulted from applying various durations of inactivity. If, for example, a given duration resulted in subjects averaging more than two nonwear periods per day, the duration was considered to be too short to identify nonwear.

Previously published studies have reported minimum durations of inactivity ranging from 10 to 60 minutes to identify nonwear periods (12–29). However, for this study, we reasoned a 60 minute duration might be too short for two reasons. First, unlike a hip-mounted accelerometer that can register counts when a subject changes sitting positions, the SAM only registers activity when a step-like motion is taken. Second, bariatric surgery candidates might have longer sedentary periods than the general population (33). Consequently, durations of at least 60, 90, 120 and 150 continuous minutes of inactivity were examined, with the plan to consider either shorter or longer durations if the resulting estimates of nonwear and wear periods from all of these durations were unreasonable.

Step counts at the minute level were exported from the manufacturer software to SAS software, version 9.1 (SAS Institute Inc, Cary, NC). The data were examined at the minute level starting with the first minute of the first day and ending with the last minute of the last day of monitor wear to identify inactive periods, defined as periods with no steps, of at least 60, 90, 120 or 150 minutes, respectively. This was done so that inactive periods of at least the specified duration starting one day and ending the next (e.g., 23:30 to 07:00) would be identified even if a portion of the inactive period was shorter than the minimum duration at the day level (e.g., 23:30 to 24:00). To estimate how many inactive periods of at least the specified duration were nonwear periods, as opposed to sleep periods, inactive periods

starting before 06:00 or including 23:59 were considered sleep periods, whereas inactive periods of at least the specified duration starting after 06:00 and not including 23:59 were considered to be nonwear periods (Figure 1). Although it was possible for awake nonwear periods to be misclassified as sleep periods and vice versa with this classification scheme, visual inspection of the data indicated that this was probably rare. After each minute was categorized as being in a wear period or not, the data were organized at the day level to calculate daily wear time as the number of minutes in wear periods.

Activity monitor data reduction

The data were screened for signs of monitor malfunction. In particular, extreme values for number of steps at the minute level and at the day level were reviewed. The distribution of steps at the minute level revealed no signs of unreasonably high step counts; no one had more than 152 steps in any minute. A visual inspection of the data of subjects in the top three percent of mean daily step counts indicated that the high values were likely a result of high levels of PA since subjects had a consistent level of PA across days, were active a high percentage of time, and had reasonable variability in minute to minute step counts. However, the data of 16 subjects from the bottom three percent of mean daily step counts indicated that it was likely that either the monitor did not record steps properly or was not worn. The latter was more likely the case since all monitors were returned in working order. These subjects were excluded from analyses.

Five data reduction algorithms were applied to the data of the remaining 1064 subjects. The first four algorithms used durations of inactivity of at least 60, 90, 120 or 150 minutes, respectively, to identify sleep and nonwear. These rules were coupled with a commonly used wear time requirement of at least four days with at least 10 hours of wear (23). When a subject had more than seven days with at least 10 hours of wear, only the first seven days were selected.

The fifth data reduction algorithm utilized the diary data with valid days defined as days with fewer than five hours of reported monitor removal. As above, at least four valid days were required. Because the diary did not capture sleep time, monitor wear time could not be calculated with the diary data so wear time was estimated with monitor data as the time from the first step of the day to the last step of the day.

Physical activity measures

Five PA measures were calculated: mean daily steps: sum of steps across days divided by the number of days; mean daily active minutes: sum of minutes with at least one step across days divided by the number of days; peak PA index: sum of steps during the most active 30 minutes of each day (continuous or non-continuous) divided by 30, divided by the number of days; mean steps per minute: sum of steps across days divided by the number of wear time minutes across days; mean percent time active: sum of minutes with at least one step across days divided by the number of wear minutes across days.

Statistical analysis

For each of the four algorithms employing a monitor-based wear time decision rule, each subject's highest number of nonwear periods in a single day, mean number of daily nonwear periods, highest number of wear periods of less than an hour in a single day and mean number of daily wear periods of less than an hour were calculated. Days that met the valid day definition with at least one algorithm but not another and days with three or more nonwear periods from each algorithm were visually examined for indications of misclassification, such as nonwear periods occurring one after the other with little activity in between.

Generalized Estimating Equations (GEE) with an unstructured correlation matrix for repeated measurements were used to test whether the number of valid days, daily wear time, and the various PA measures differed according to which algorithm was applied. Pair-wise p-values were adjusted for multiple comparisons using Holm's step-down method (34). Statistical significance was defined by $p < .05$. All analyses were conducted with SAS, version 9.1 (SAS Institute Inc, Cary, NC).

RESULTS

Subject characteristics are shown in table 1. Subjects were primarily female and white, with an average age of 45 years and a median BMI of 46 kg/m². Nearly two thirds of the subjects were married or living as married. Over three-fourths (78.2%) of the sample had at least some post-high school education and over one third (37.0%) had a college degree. Eleven point nine percent used a cane, walker, scooter, or wheelchair, at least some of the time.

Determining a wear time decision rule

The shortest minimum duration of inactivity used to identify nonwear (60 minutes) resulted in unreasonably large percentages of subjects with unlikely wear patterns, i.e., at least three nonwear periods in a day (29.9%), an average of more than one nonwear period per day (33.0%), and at least two wear periods of less than an hour in a day (28.7%). There was a substantial reduction in these percentages with both the 90 minute duration and the 120 minute duration (table 2). The 90 minute duration still resulted in nearly 5% of subjects with three or more non-wear periods in a single day and nearly 6% with at least 2 wear periods of less than an hour in a single day, compared to less than half a percent and less than 2%, respectively, with the 120 minute duration.

A visual inspection of days with fewer than 10 hours of wear when a shorter minimum duration of inactivity was used to identify nonwear, but at least 10 hours of wear when a longer minimum duration was used to identify nonwear showed that many wear periods were probably misclassified as nonwear periods with the shorter minimum duration. This was presumed to be the case when a very short wear period was sandwiched between two nonwear periods or a nonwear and a sleep period. For example, in Figure 2a, applying the 60 minute duration identified four wear periods, including two short wear periods between either two nonwear periods or between one nonwear and one sleep period. In comparison, with the same data the 150 minute duration resulted in one wear period followed by a sleep period (Figure 2d). Visual inspection of valid days with three or more nonwear periods revealed frequent suspiciously short wear periods occurring between sleep and nonwear periods or two nonwear periods (e.g., Figure 3). In addition, visual inspection revealed that many of these days never had sleep or nonwear periods of more than five hours, indicating frequent and possibly continuous wear.

Impact of the wear time decision rule

Table 3 shows the numbers and percentages of subjects meeting the wear time requirement and the mean number of valid days and mean daily wear time of those subjects for each algorithm. The percentage of subjects who met wear time requirements of at least 10 hours per day for at least four days, increased from 65.8% with the 60 minute cut point to 77.0% with the 150 minute cut point. Similarly, the number of valid days and the estimated mean wear time of valid days were significantly higher with higher cut points, though the number of valid days with the 120 and 150 minute cut points did not differ significantly ($p = .53$).

Fifteen percent of subjects (N=164) did not return a diary, and 39.1% those with diary data (N=352) did not complete the question assessing hours of monitor removal on at least one

day in which they wore the monitor. For the 740 (69.5%) who met the requirements of the diary-based algorithm, estimated wear time, which was calculated as the time from the first to the last step, was significantly higher than estimated wear time resulting from the monitor-based algorithms that subtracted nonwear periods.

The wear time decision rule also significantly affected PA estimates such that subjects appeared to be more active when a shorter duration of inactivity identified nonwear (Table 3). For example, on average, 616 more mean daily steps were counted with the 60 minute cut point (8205.2) than with the 150 minute cut point (7589.6, $p<.0001$). As in table 1, the greatest differences occurred between the 60 and 90 minute cut points (on average, 349 mean daily steps), with about half that difference between the 90 and 120 minute cut points (on average, 184 mean daily steps). All pair-wise comparisons of mean daily steps between algorithms were statistically significant.

Mean steps per minute and mean percent time active, which are both directly calculated with wear time, were more affected by the wear time decision rule than the other PA measures. For instance, mean steps per minute ranged from 10.0 steps/min with the 60 minute cut point to 8.6 steps/min with the 150 minute cut point, a 14% decline, with each cut point value differing significantly from all others ($p<.0001$), while the peak PA index only dropped from 75 steps/min at the 60 minute cut point to 73 steps/min at the 150 minute cut point, a 2.7% decline, with only the 60 minute cut point value differing significantly from the others ($p<.0001$). Similarly, all comparisons of percent time active differed significantly ($p<.0001$), whereas there was no significant difference between mean active minutes per day with the 120 and 150 minute cut points ($p=.13$). All PA measures resulting from the diary-based wear time rule were significantly lower than PA measures based on any of the activity monitor-based wear time rules ($p<.0001$).

DISCUSSION

Though determining activity monitor nonwear is required to accurately estimate wear time, which affects PA measures, until recently few studies reported decisions rules for determining how, or even if, nonwear was identified (23). While it has become increasingly common for studies to describe such decision rules, they have not always been data driven. Of 18 studies published since 2003 that have reported a minimum duration of monitor inactivity to identify nonwear (12–29), only four described their method for selecting a duration (12;13;19;27). All four studies utilized a duration of 20 minutes with the following rationale: 1) awake children wearing an accelerometer do not record consecutive zero counts for more than 20 minutes (27); 2) the monitor records the slightest motion (13); 3) the mean length of subjects' longest bout of inactivity (17.5 min) informed their decision (19); 4) the duration was supported by unpublished data regarding the maximum number of consecutive zeros associated with inactivity (12). However, no details were provided. The absence of justification or support for minimum durations of inactivity in previously published studies, and the recognition that population and monitor specific durations may be optimal, suggested that there needs to be a methodology for examining activity monitor data to identify nonwear.

Determining a wear time decision rule

Of the four minimum durations of inactivity used in this analysis to identify nonwear, the shortest duration of 60 minutes was inappropriate due to the resulting high number of nonwear periods and short wear periods in a day. At the other extreme, the 150 minute cut point gave what was considered to be too high of an estimate of the number of people who never took the monitor off during the day (61%). However, without knowing the true frequency of nonwear periods, other data were examined including the percentage of

subjects with two or more wear periods of less than an hour on a single day, a scenario which is considered to be unlikely. The 60 and 90 minute durations both resulted in percentages considered to be too high. Visual inspection of the data also added valuable insight. For example, the 60 and 90 minute durations both frequently resulted in a pattern of several nonwear periods occurring one after the other with only short wear periods in between (Figure 2) suggesting that many subjects were, in fact, inactive for at least 90 minutes at a time. Finally, in general, days with three or more nonwear periods had several unreasonably short wear periods (Figure 3), confirming the concept that the selected duration should rarely result in three nonwear periods in a single day.

An interval of at least 120 minutes of inactivity to identify sleep and nonwear in bariatric surgery candidates using the SAM monitor yields reasonable estimates of nonwear periods per day and durations of active periods. It is important to note that while the approach to examining data outlined here is universal, different populations or different monitors will likely yield different optimal decision rules to determine wear time (23). Obesity may influence durations of active and sedentary periods (33) and adults may remain sedentary for longer durations than children (23). Thus, it may be more appropriate to use a shorter minimum duration of inactivity to identify nonwear with children or normal weight adults compared to severely obese adults. In addition, the force required to register a count or step varies considerably across monitors, depending on the number of planes in which movement is measured and monitor placement (35). While extremely accurate at measuring steps, the activity monitor used in this study does not register movement of the trunk, as many hip-mounted accelerometers do. Thus, the optimal cut point to identify nonwear in more sensitive monitors may be shorter whereas those in less sensitive monitors may be longer.

An additional source of variation to consider is the individual monitor. While most activity monitors in use today are very dependable, testing the ability of monitors to measure a movement standard before each use has been recommended to ensure proper calibration (36). Finally, the unit of time (epoch length) serving as the denominator for steps/unit time should be considered. It is unlikely that epochs of a minute or less will have much impact on determining wear time when nonwear is defined as inactivity for at least 20 minutes. However, it is possible that longer epoch lengths will underestimate nonwear periods by misclassifying inactive fragments of epochs as being part of an active epoch.

To date, within populations or monitors, there is substantial variability in minimum durations of inactivity to identify nonwear. For example, studies using the ActiGraph model 7164 have reported durations ranging from 10 to 60 minutes to identify nonwear in children (15;16;19;25;27–29), with a similar range of 15 to 60 minutes seen in studies of adults (14;20–24;26;29). Applying the methodology described in this paper may lead to more consistency across studies investigating similar populations with the same monitor. At the least, critically examining the frequency and distribution of nonwear periods and the duration of wear periods that result from applying various durations of inactivity to identify nonwear will lead to greater consistency in how inactive periods are evaluated and handled in data processing (e.g., prevent use of cut points that result in unlikely numbers of nonwear periods or very short wear periods).

It is impossible to find a minimum duration of inactivity that best differentiates wear periods from nonwear and sleep periods for all subjects since some subjects will have longer bouts of sedentary activities than others. It may also be impossible to find one minimum duration of inactivity that correctly identifies all nonwear and sleep periods for an individual since a subject may have some nonwear periods that are shorter than bouts of sedentary activities during wear periods. Thus, any duration used to identify nonwear will result in some misclassification. Minimizing misclassification of long wear periods as nonwear periods is

paramount because otherwise compliant subjects will be removed from analysis. However, this comes at the expense of misclassifying short nonwear periods as wear periods.

Effect of the wear time decision rule

Because the decision rule to determine wear time impacts which subjects, days, and minutes are included in PA analyses, it in turn affects PA estimates. The diary-based wear time rule resulted in PA measures that were significantly lower than PA measures resulting from any of the activity monitor-based wear time decision rules by a margin greater than that seen between any of the monitor-based wear time decision rules. Given this discrepancy, using a diary-based decision rule is not recommended.

While all PA measures were affected by the wear time decision rule, the degree of the effect differed. PA measures that did not directly take wear time into account, e.g., mean active minutes per day, were affected less than PA measures that required wear time to calculate, e.g., percentage of wear time being active, and thus may be preferred PA measures, given that wear time is in fact an estimate. These findings are consistent with another study which found that a shorter duration of inactivity to identify nonwear periods (20 vs. 60 minutes) resulted in higher estimates of all PA measures, with the greatest impact on counts per minute (23).

In this study, just over three fourths of subjects had four days with at least 10 hours of wear when the 120 minute rule was applied. This is markedly less than the proportion of subjects reported to have at least four valid days of accelerometer data in the 2003–04 National Health and Nutrition Examination Survey (NHANES) (29). One possible reason for this discrepancy is that a quarter of LABS subjects had fewer than seven days to wear the SAM before proceeding to surgery. Another is that there may have been more discomfort of the ankle worn device attached by a Velcro strap among these severely obese subjects than in the general population. While not the focus of the current effort, an unpublished examination of factors potentially related to meeting the wear requirement found no response bias by sex or age.

Limitations

Allowing subjects to wear the activity monitor continuously made classification of wear, nonwear and sleep periods more difficult since the monitor registers even brief bouts of activity (e.g., a short bathroom break) within what are primarily sleep periods. The classification scheme we employed would misclassify awake nonwear periods starting before 06:00 and including 23:59 as sleep periods, and sleep periods starting after 06:00 and ending before 23:59 as nonwear periods. Fortunately, such misclassification probably had little effect on cohort estimates of nonwear periods, and no effect on estimates of wear time, which excludes both sleep and nonwear periods. Since a continuous wear protocol should result in high wear compliance the benefit of continuous wear probably outweighs the added complexity of classifying nonwear and sleep periods. Future studies that allow or mandate a continuous wear protocol should record self-report of tolerance of continuous wear.

Conclusion

A method for examining activity monitor data to determine an appropriate duration of inactivity to identify nonwear and sleep periods is described which can be repeated in other studies. Specifically, when choosing a wear time decision rule researchers should aim to minimize the number of people that: 1) have two or more nonwear periods in a single day; 2) average more than one nonwear period per day and 3) have two or more wear periods of less than an hour in a single day. Following this approach, we found that at least 120 minutes of inactivity should be used to identify nonwear periods. However, this finding is

specific to adult bariatric surgery candidates wearing the SAM. Following these methods in a different population or with a different monitor will likely yield different results. Thus, population and instrument specific lengths of inactivity to identify nonwear periods are probably needed. The decision rule to determine wear time impacts which subjects, days, and minutes are included in PA analyses, which in turn affects PA estimates. Recognizing that monitor wear time is estimated, PA measures least affected by wear time are preferable.

Future Research

Due to the importance of accurately defining this aspect of activity monitor use, research should continue in this area. Researchers should facilitate comparisons of results across studies by clearly describing their decision rules and in particular, reporting the frequency of nonwear periods resulting from their decision rule to identify activity monitor wear time.

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a. Day with 1 sleep period and 1 nonwear period; wear time = 10.1 hours.

b. Day with 2 sleep periods and 1 nonwear period; wear time = 10.6 hours.

c. Day with 2 sleep periods and 1 nonwear period; wear time = 15.8 hours.

Figure 1.
Identifying sleep and nonwear periods by detecting continuous bouts of inactivity of at least 120 minutes.

- a. A 60 minute duration results in 2 sleep periods, 3 nonwear periods, and a wear time of 7.8 hours.

- b. A 90 minute duration results in 2 sleep periods, 2 nonwear periods and a wear time of 8.9 hours.

- c. A 120 minute duration results in 2 sleep periods, 1 nonwear period and a wear time of 10.5 hours.

d. A 150 minute duration results in 2 sleep periods, 0 nonwear periods and a wear time of 12.7 hours.

Figure 2.
Applying four minimum durations of inactivity to identify nonwear to the same day.

a. A 60 minute duration results in 5 nonwear periods with 3 wear periods of less than 12 minutes each.

b. A 90 minute duration results in 4 nonwear periods with 3 wear periods of less than 16 minutes.

c. A 120 minute duration results in 3 nonwear periods with 3 wear periods of less than 47 minutes.

Figure 3.
Days with at least three nonwear periods resulting from various durations of inactivity to identify nonwear.

Table 1

Characteristics of Subjects (N=1064)

Female; N (%)	848 (79.7%)
Race; N (%)	
White	928 (87.4%)
Black	95 (9.0%)
Other	39 (3.7%)
Missing	2
Hispanic; N (%)	64 (6.0%)
Age (years); Mean $\pm$ sd	44.6 $\pm$ 11.4
Age group (years)	
<30	106 (10.0%)
30–<40	281 (26.4%)
40–<50	284 (26.7%)
50–<60	287 (27.0%)
60	106 (10.0%)
BMI (kg/m ²); Median (25 th –75 th %)	46.0 (42.2 – 51.6)
BMI group (kg/m ²); N (%)	
<40	151 (14.2%)
40–<50	576 (54.1%)
50–<60	266 (25.0%)
60	71 (6.7%)
Married/living as married; N (%)	642 (62.8%)
Missing	41
Education; N (%)	
Some high school	28 (2.7%)
High school diploma/GED	194 (19.0%)
Some college	421 (41.2%)
College diploma	378 (37.0%)
Missing	43
Sometimes use a cane, walker, scooter, or wheel chair; N (%)	119 (11.9%)
Missing	65

SD =standard deviation; BMI = body mass index; GED = General Educational Development

Table 2

Nonwear and wear periods resulting from 4 wear time decision rules and a typical wear requirement of 10hrs of wear for 4 days (n=1064).

	Duration of inactivity to identify nonwear periods (minutes)			
	60	90	120	150
Number of subjects meeting wear requirement	700	768	804	819
Max # nonwear periods in a single day, %				
0	5.7	20.1	41.0	61.2
1	30.1	53.8	49.5	37.0
2	34.3	21.4	9.1	1.8
3	19.3	4.6	0.4	0
4	10.6	0.3	0	0
Mean # daily nonwear periods, %				
1	67.0	94.4	98.7	99.6
>1-2	26.6	5.3	1.2	0.4
>2	6.4	0.3	0	0
Max # wear periods <1 hour in a single day, %				
0	23.3	50.3	70.8	83.3
1	48.0	43.8	27.4	16.5
2	21.4	5.3	1.6	0.2
3	7.3	0.6	0.3	0
Mean # daily wear periods <1 hour, %				
0	23.3	50.3	70.8	83.3
>0 – 0.5	48.7	43.6	27.6	16.7
>0.5 – 1	22.7	5.7	1.6	0
>1	5.3	0.4	0	0

Table 3

Wear-time estimates and physical activity measures (n=1064)

	Wear time decision rule					Wald test P-value
	Duration of inactivity to identify nonwear (minutes)				Diary	
	60	90	120	150	<5 hrs removal	
Subjects meeting wear time requirement (n, % cohort)	700 ² (65.8%)	768 ² (72.2%)	804 ² (75.6%)	819 ² (77.0%)	740 ³ (69.5%)	
# of valid days	5.77 (0.04) ^a	5.88 (0.04) ^b	5.93 (0.04) ^c	5.98 (0.04) ^c	6.10 (0.04) ^c	<0.0001
Mean daily wear-time (minutes)	821.7 (2.9) ^a	853.9 (3.1) ^b	874.8 (3.5) ^c	892.2 (3.9) ^d	972.4 (7.7) ^e	<0.0001
Physical Activity Measures						
Mean daily steps	8205.2 (119.2) ^a	7856.1 (114.0) ^b	7671.9 (112.3) ^c	7589.6 (111.4) ^d	7154.5 (113.0) ^e	<0.0001
Mean daily active minutes	332.8 (3.5) ^a	320.0 (3.4) ^b	312.7 (3.4) ^c	309.5 (3.4) ^c	292.4 (3.6) ^d	<0.0001
Peak PA index (mean steps/min for most active 30 min)	75.3 (0.6) ^a	73.9 (0.5) ^b	73.1 (0.5) ^c	72.7 (0.5) ^{bc}	70.0 (0.6) ^d	<0.0001
Mean steps per minute	9.98 (0.14) ^a	9.22 (0.13) ^b	8.81 (0.13) ^c	8.58 (0.13) ^d	7.74 (0.13) ^e	<0.0001
Mean percent time active	40.4 (0.4) ^a	37.5 (0.4) ^b	35.8 (0.4) ^c	34.9 (0.4) ^d	31.5 (0.4) ^e	<0.0001

¹ Mean (SE) reported unless otherwise noted² At least 10 hours of wear on at least four days³ Less than five nonwear hours reported on at least four days

Values with the same letter (a, b, c, d, e) are not statistically significantly different in pair-wise comparisons