Objective and Subjective Measures of Sedentary Behavior and Physical Activity

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[1]*Human Movement Sciences, College of Health Sciences, University of Wisconsin-Milwaukee, Milwaukee, WI;* [2]*College of Nursing and Health Innovation, Arizona State University, Mesa, AZ; and* [3]*Walking Behavior Laboratory, Pennington Biomedical Research Center, Baton Rouge, LA*

ABSTRACT

HART, T. L., B. E. AINSWORTH, and C. TUDOR-LOCKE. Objective and Subjective Measures of Sedentary Behavior and Physical Activity. *Med. Sci. Sports Exerc.*, Vol. 43, No. 3, pp. 449–456, 2011. **Purpose**: To examine the convergent validity of the ActiGraph and activPAL accelerometers with the Bouchard Activity Record (BAR) in adults. Sedentary behavior and walking were evaluated in all instruments; standing and moderate-to-vigorous physical activity (MVPA) was evaluated only in those that detected such variables. **Methods**: Thirty-two participants wore the accelerometers and completed the BAR concurrently for 1 d. Descriptive statistics and delta values were reported for all instruments. Summary time spent in sedentary behavior and walking was compared between all instruments using repeated-measures ANOVA. Dependent *t*-tests were used to analyze summary time in 1) standing between activPAL and BAR and 2) MVPA between ActiGraph and BAR. Bland–Altman plots were interpreted for systematic bias. On a detailed level, concurrent time interval data were compared using mean percent agreement and κ statistics. **Results**: There was a significant difference found in summary time spent in sedentary behavior apparent between ActiGraph and activPAL as well as between ActiGraph and BAR. There was also a significant difference detected in time spent in walking, apparent between ActiGraph and activPAL, and between ActiGraph and BAR. In the time interval analysis, mean percent agreement ranged from 54.0% (for walking detected by ActiGraph and activPAL) to 86.7% (for MVPA by ActiGraph and BAR). κ values ranged from 0.25 (for walking by ActiGraph and activPAL) to 0.70 (for sedentary behavior between activPAL and BAR). Differences were also found in standing and MVPA. **Conclusions**: The activPAL and BAR showed convergence on both summary and concurrent time interval levels in both sedentary behavior and walking. The comparative discordance between activPAL and BAR with ActiGraph was likely a function of different approaches used to distinguish sedentary behavior from walking. **Key Words:** SITTING, WALKING, ACCELEROMETER, ADULT

Researchers are seeking optimal ways to assess physical activity (PA) and sedentary behaviors with the continued interest in understanding the potentially deleterious health effects of these types of behaviors in adults (9). Activities such as sitting, lying, sleeping, and watching television are collectively considered to be sedentary behaviors (20). Accelerometers have been used to assess PA by intensity levels (10,11,17); however, fewer studies have used accelerometers to assess sedentary behaviors. Matthews et al. (17) used cut points to interpret ActiGraph accelerometer (ActiGraph LLC, Pensacola, FL) data and capture time spent in sedentary behaviors from age 6 yr and older in the 2003–2004 National Health and Nutrition Examination Survey study. Objectively assessed sedentary behavior has also been linked to deleterious health outcomes. Associations were significant independent of PA in a study relating ActiGraph accelerometer–assessed sedentary behavior with clustered metabolic risk (11). The activPAL Professional accelerometer (PAL Technologies Ltd., Glasgow, UK) is a relatively new accelerometer option that uses inclinometer technology to assess sedentary behavior (i.e., sitting/lying), standing, and walking time. Self-report surveys and logs have also been used to assess PA (16) and sedentary behaviors (3,12); however, the results have limited comparability with more objective measures (e.g., accelerometers). Most questionnaires have focused on specific behaviors, such as television watching, rather than a more encompassing estimate of sedentary behaviors (5). The Bouchard Activity Record (BAR) is a PA log that can be used to assess self-reported time in sitting, lying, and standing activities as well as PA (2).

The comparison of subjective measures and objective measures (e.g., using accelerometers) of PA and sedentary behavior is limited, and there is concern that their outputs may not reflect similar parameters (4). The purpose of this study was to examine the convergent validity of ActiGraph, activPAL, and BAR to assess both PA and sedentary behaviors in adults. Specifically, we evaluated the comparable outputs from each instrument for PA (e.g., walking and

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Submitted for publication February 2010.
Accepted for publication June 2010.

0195-9131/11/4303-0449/0
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

DOI: 10.1249/MSS.0b013e3181ef5a93

moderate-to-vigorous PA (MVPA)), standing, and sedentary behavior expressed as total minutes per day (i.e., summary level) and for every 15-min concurrently recorded interval in healthy, physically active adults under free-living conditions. This information will improve our understanding regarding the strengths and limitations of these various instruments used to assess multiple PA and sedentary behaviors in "real time" and to show absolute differences in time estimates between instruments.

METHODS

Participants

Participants were recruited from the Arizona State University Polytechnic campus and the surrounding areas. Inclusion criteria included self-identified runners (to ensure a broad range of PA and sedentary behaviors for each instrument) who intended to run on the monitored day. This strategy was successfully used in a previous instrumentation study (18) to ensure that all PA intensities were captured and could be compared. In addition, participants who were 18–60 yr old, had a body mass index (BMI) <30 kg·m^{-2}, and could read, speak and understand English were included in the study. On the basis of a power calculation for an α of 0.05 and a β of 0.20 that included a 15% dropout rate (i.e., incomplete data or instrument malfunction), it was estimated that 36 ostensibly healthy adults were needed in this study. This study was approved by the Arizona State University's Institutional Review Board, and written informed consent was obtained before data collection.

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Instrumentation

ActiGraph GT1M. Although recently removed from production, the ActiGraph model GT1M (previously distributed as CSA or MTI) used in this study provides information on frequency, intensity, and duration of PA by using a built-in single-axis accelerometer, which measures vertical accelerations at the hip. This instrument has been validated as an accurate measure of frequency, intensity, and duration of PA (7,19). A comparison of the GT1M model with models used in previous validation studies showed no differences in the activity counts produced by both instruments (13). Detailed technical specifications for ActiGraph are provided elsewhere (7). Accelerations detected by ActiGraph are summed internally and stored over a preset, user-determined epoch (i.e., time sampling interval) ranging typically from 1 s to several minutes. The resulting outputs from ActiGraph are activity counts and steps per epoch. As indicated above, activity intensity is then derived from the activity counts based on previously validated cut points. For example, the most commonly used cut point for MVPA in healthy adults is 1952 activity counts per minute (7). ActiGraph also has specific cut points for sedentary behavior such as <100 activity counts per minute (17). The use of this cut point enables researchers to estimate time spent in all sedentary behaviors, such as sitting, reclining, or lying down. Although this cut point has not been validated as a threshold for sedentary behaviors, it assesses nonmovement time and it cannot be used to differentiate sitting from other sedentary behaviors. For example, at least in theory, a person could be sitting (a sedentary behavior) and fidgeting, which could result in >100 counts per minute and be classified as PA. Alternatively, a person could be standing completely motionless (a nonseated behavior), which could result in <100 counts per minute and be classified as sedentary.

activPAL Professional. The activPAL uses a single-axis piezoresistive accelerometer. Detailed technical specifications for activPAL are provided elsewhere (21). Briefly, the activPAL has the memory and battery life capacity to collect and store data for >8 d; the battery can recharge from full discharge in 2 h. The activPAL connects to a personal computer via a USB port and a docking station. It is initialized and downloaded using proprietary software produced by the manufacturer. The software generates pictorial representations of behavior by day or by week, and raw data can be exported to a spreadsheet for analysis. Data are detected and summed during a preset 15-s epoch and are outputted as time spent in sedentary behavior, standing, walking, number of steps, and estimated energy expenditure per 15-s epoch. These epochs are then summed for a day to derive accumulated time spent in each posture or behavior. Additional outputs include time in stepping by cadence (i.e., steps per minute), length of bouts of sit/lie and standing, and a count of sit-to-stand transitions. In a directly observed study of free-living behavior with young adults (mean age = 24.9 ± 1.7 yr), the activPAL was 98% accurate in a study measuring both static (i.e., sitting and standing) and dynamic behaviors (i.e., walking) (8). In a laboratory-based study, it also was accurate (<1.11% absolute error) in detecting step count and walking cadence (i.e., steps per minute) in young adults (mean age = 34.5 ± 6.9 yr) during five treadmill speeds and three outdoor self-selected speeds (21). The activPAL is not able to differentiate sitting from lying however. Regardless, both ActiGraph and activPAL provide useful information regarding walking and sedentary behavior but may be more challenging to use in large-scale applications because of their relatively high costs (US\$299 for the current model of ActiGraph; ~US\$570 for activPAL Professional).

Bouchard activity record. BAR is a self-report instrument that assesses all levels of the PA spectrum from lying and sitting to vigorously intense PA (2). It is a pen-and-paper tool that consists of a table representing a single day with 15-min intervals spanning a 24-h period. Each behavior is given a numeric assignment on the basis of the estimated energy expenditure of that activity ranging from "1" to "9," with "1" being the least intense behavior (e.g., lying or sleeping) and "9" being extremely intense exercise (e.g., running in a race). Total daily time walking, MVPA, standing, and sedentary behavior can be determined by the summation of all 15-min cells in each behavior. For example, total sitting time for the day in minutes can be determined by adding the number of cells containing a "2" and multiplying it by 15. BAR is suitable for estimating energy expenditure (2) and has shown a strong correlation between its PA outputs with the TriTrac accelerometer (r = 0.72) (23). Schmidt et al. (22) also reported a weak correlation of BAR estimates of PA with the ActiGraph (r = 0.23).

Procedures

Participants completed two study visits. During the first visit, height and weight were measured using standardized procedures (1). Participants were instructed to attach the accelerometers on waking (or immediately after bathing or showering) the day after the first visit and to wear them all waking hours. Participants were asked to perform their usual activities, including at least 30 min of running as per their regular habit, and to record on the BAR exact wear time of the two accelerometers.

The ActiGraph was worn on the right midaxillary line of the hip on an elastic belt. The activPAL was affixed to the front of the right thigh with a hypoallergenic double-sided adhesive pad (i.e., comfortably affixing to both the accelerometer and skin) and a piece of cloth medical tape over the top to ensure that the instrument stayed in place. Both accelerometers were initialized before distribution, and data for both were collected at a 15-s epoch (driven by epoch limitations of activPAL) to facilitate direct comparison.

To complete the BAR, the participant was asked to fill in each table cell with a number that corresponded to a specific behavior that he or she was currently performing. A list of sample behaviors in each numeric category (i.e., 1–9) was written on the same page as the table to facilitate completion. Participants were asked to report the primary activity performed during the 15-min interval. For example, if during a 15-min period, a participant performed sitting and typing for 10 min and standing for 5 min, they would report 15 min of sitting. For this study, the activity of "driving a car" was reassigned from level "4" (original to BAR) to a level "2" activity to be more similar to other behaviors performed in a seated position.

During the second visit, participants returned the instruments and were asked about any problems with the measurement process. The researcher also went through the BAR in detail with the participant to ensure that it was complete and accurate.

Data Treatment

The accelerometers were downloaded as per the manufacturers' instructions. For comparison purposes, each of the PA and sedentary behaviors assessed (e.g., sedentary behavior, standing, walking, MVPA) were defined *a priori* for each of the three instruments, bearing in mind their unique individual measurement parameters. See Table 1 for a side-by-side presentation of the variables that were compared between each of the instruments. Data from the ActiGraph and activPAL were screened for nonwear (i.e., runs of ≥60 consecutive "zeros" were removed); however, no data were removed from this process. Because the ActiGraph does not have the capability of differentiating postures, a cut point of <100 activity counts per minute was considered indicative of sedentary behavior (6,10,17). Activity counts ≥100 $\min^{-1}$ from the ActiGraph were considered to be ambulation of some intensity (i.e., walking), and activity counts ≥1952 $\min^{-1}$ were considered indicative of MVPA (i.e., a subcomponent of walking) (7). Data for activPAL were outputted as time (down to 0.1 of a second) in sit/lie, stand, and stepping (i.e., walking) for each epoch using the activPAL proprietary software. Time for the total day was summed for each behavior, as well as for each 15-min sampling interval.

Summary Analysis

The goal of the analysis of summary data was to compare ActiGraph, activPAL, and BAR in multiple behaviors by reducing the data into similar units (Table 1). Total time detected for the monitored period by each instrument was compared between instruments for each of the variables evaluated.

Concurrently Collected Time Interval Analysis (15-min Intervals)

For this analysis, data were evaluated in 15-min time intervals driven by the minimum time intervals recorded on the BAR. ActiGraph data were recoded to assign a specific variable to each 15-min time interval on the basis of the aforementioned cut points. For example, if the total counts for the 15-min time interval divided by 15 (i.e., to get average counts per minute) was greater than 1952, that interval was classified as MVPA. For activPAL, the behavior with the greatest amount of time in each 15-min time interval was considered the primary one for comparison. For example, if the activPAL detected 3.2 min of sedentary behavior,

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TABLE 1. Cut points for ActiGraph, activPAL Professional, and the BAR.

	ActiGraph	activPAL	BAR
Sedentary behavior	<100 activity counts per minute	Time in sitting/lying	Categories 1 and 2
Standing	N/A	Time in standing	Category 3
Walking	≥100 activity counts per minute	Time in walking	Categories 4–9
MVPA	≥1952 activity counts per minute	N/A	Categories 5–9

ActiGraph does not have the capability of detecting time in standing behaviors specifically, and activPAL does not have the capability of detecting time in MVPA and, as such, is denoted as N/A (not applicable).

10.9 min of standing, and 0.9 min of walking, the overall time interval would be considered representative of standing.

Statistical Analyses

All summary data were tested for normality using plots and Shapiro–Wilk's tests. Descriptive data were reported as means ± SD. In addition, ranges and mean delta values (e.g., ActiGraph − BAR, activPAL − BAR, activPAL − ActiGraph) were reported. For inferential analysis, data were transformed using log transformations if they were nonnormal. A value of 1 was added to zero values to avoid applying logarithms to zero values. Summary data for time spent in walking and sedentary behavior were compared between instruments using a separate repeated-measures ANOVA for each variable. Where appropriate, *post hoc* pairwise comparisons were used to determine where differences occurred between instruments. Where only two instruments detected a similar variable, dependent *t*-tests were used to analyze summary data (e.g., time spent in standing between activPAL and BAR, and MVPA between ActiGraph and BAR). Spearman's rank correlations were performed between all instruments for each variable. In addition, Bland–Altman plots were used to evaluate bias between pairs of instruments between instruments that could detect time in each variable.

Concurrently Collected Time Interval Analysis

Time interval data were analyzed by mean percent agreement using binary coding between each pair of instruments for each 15-min interval. For example, if both the ActiGraph and the BAR indicated sedentary behavior for the same time-stamped 15 min interval, then "1" was assigned to represent agreement. Zero was used to represent no agreement (e.g., sedentary behavior detected by the ActiGraph and walking detected by the BAR). The mean percent agreement for all time intervals and for all participants was calculated for the monitored period for walking and sedentary behavior (all instruments), standing (activPAL and BAR), and MVPA (ActiGraph and BAR). κ statistics were computed as another indication of agreement.

RESULTS

Data quality. Analyses were performed using data from 32 of the originally recruited 36 participants because of incomplete data collected for four participants. No activPAL data were recorded for one participant, the ActiGraph was not properly initialized for one participant, another had an incomplete BAR (which did not match accelerometer time worn), and the fourth participant reported that the activPAL fell off during the day. No other problems were reported. All participants reported taking at least a 30-min run during the monitoring period. The analysis sample included 16 men (age = 29.1 ± 7.9 yr, BMI = 23.8 ± 2.3 kg·m^{-2}) and 16 women (age = 30.2 ± 9.5 yr, BMI = 22.2 ± 2.6 kg·m^{-2}). Mean ± SD self-reported wear time of the accelerometers was 15.2 ± 1.8 h; mean ± SD time detected by the ActiGraph was 15.1 ± 1.9 h and that by the activPAL was 15.0 ± 2.0 h.

Summary analysis. For the analysis of summary data, time in each variable (sedentary behavior, standing, walking, MVPA) for each instrument is presented in Table 2 as mean ± SD (range). All non–normally distributed variables were log-transformed for inferential analysis. Mean time detected in walking ranged from 18.2% (2.8 h) of the monitored time by activPAL to 28.5% (4.3 h) by ActiGraph. Mean time detected in sedentary behavior during the monitored time ranged from 53.7% (8.1 h) as detected by the BAR to 71.8% (10.8 h) as detected by the ActiGraph.

The Bland–Altman plots showed no evidence of systematic bias for all pairings of instruments across all variables with the exception of activPAL and BAR for standing, activPAL and ActiGraph for walking, as well as for ActiGraph and BAR for walking. The narrowest limits of agreement were observed between activPAL and ActiGraph for walking (−48.2 to −138.1 min). Bland–Altman plots between activPAL and BAR for standing, activPAL and ActiGraph for walking, and ActiGraph and BAR for walking are presented in Figure 1.

When examining relationships for sedentary behavior, there were significant moderate correlations between all pairs of instruments ranging from 0.56 to 0.87 ($P < 0.001$ for all) with the strongest correlation occurring between activPAL and BAR. For walking, activPAL and ActiGraph were strongly and significantly correlated ($\rho = 0.98$, $P < 0.001$). Although still significant, BAR was only moderately correlated with ActiGraph ($\rho = 0.53$, $P = 0.002$) and activPAL ($\rho = 0.53$, $P = 0.002$). No other correlations were significant ($P > 0.05$).

There was a significant difference in time spent in sedentary behavior ($P < 0.001$) with *post hoc* pairwise differences

TABLE 2. Summary time in minutes for free-living behaviors monitored concurrently on a single day presented as mean ± SD (range).

	Wear Time (h)	Sedentary Behavior	Standing	Walking	MVPA
ActiGraph	15.1 ± 1.9 (11.5–19.7)	650.6 ± 111.8 (405.0–888.0)	N/A	258.3 ± 70.3 (122.0–418.0)	66.7 ± 32.1 (21.5–179.3)
activPAL	15.0 ± 2.0 (11.4–19.6)	518.5 ± 147.8^{a} (185.3–828.8)	225.3 ± 119.2 (97.0–662.0)	165.1 ± 53.6^{b} (81.8–270.3)	N/A
BAR	15.1 ± 2.0 (11.3–19.5)	487.0 ± 194.3^{a} (105.0–945.0)	176.3 ± 131.2 (30.0–555.5)	230.2 ± 153.8^{b} (60.0–795.0)	162.7 ± 163.2 (30.0–795.0)

Statistical significance was determined using repeated-measures ANOVA with *post hoc* pairwise testing where appropriate. Values with the same superscript letter in a column are not significantly different; those with no superscript are significantly different from the other instruments.
ActiGraph does not have the capability of detecting time in standing behaviors specifically, and activPAL does not have the capability of detecting time in MVPA and, as such, is denoted as N/A.

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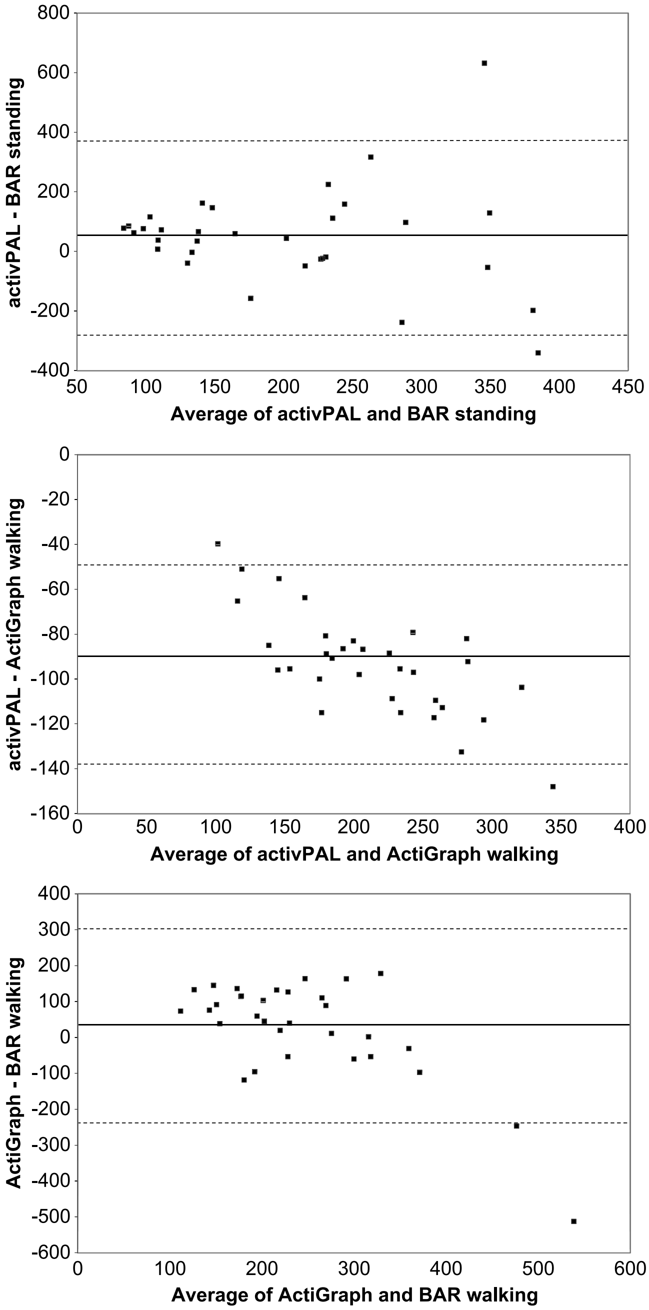

FIGURE 1—Bland–Altman plots for estimates of standing and walking.

occurring between activPAL and ActiGraph (Δ = −132.1 min) and between ActiGraph and BAR (Δ = 163.6 min). There was no significant difference in time detected in sedentary behavior between activPAL and BAR (Δ = 31.5 min). There was also a significant difference in detected amounts of time spent in walking (P < 0.001). The *post hoc* analysis showed the differences existed between activPAL and ActiGraph (Δ = −93.2 min) and between ActiGraph and BAR (Δ = 28.1 min); there was no difference in time detected in walking between activPAL and BAR (Δ = −65.0 min). The activPAL and BAR detected significantly different amounts of time spent standing (Δ = 49.0 min, P = 0.009), and ActiGraph and BAR detected significantly different amounts of time spent in MVPA (Δ = −96.0 min, P = 0.001).

Mean delta values captured both undercounting and overcounting of time in sedentary behavior, depending on which instruments were compared. For example, the mean delta values for sedentary behavior ranged from −135.6 min (activPAL − ActiGraph) to 144.9 min (ActiGraph − BAR). Regardless of direction, the smallest individual difference was observed in sedentary behavior between activPAL and ActiGraph (Δ = 2.8 min), and the largest was in MVPA between ActiGraph and BAR (Δ = 749.0 min). Table 3 contains mean delta values for each pair of instruments, as well as the range of individual minimum and maximum values.

Concurrently collected time interval analysis. An example of all three instruments for a single 15-min time interval is presented in Figure 2. Table 4 contains mean percent agreement and κ values between pairs of instruments for all variables in the time interval analysis for the monitored period. Mean percent agreement ranged from 54.0% (for walking as detected by activPAL and ActiGraph) to 86.7% (for MVPA as detected by ActiGraph and BAR). For sedentary behavior, agreement ranged from 64.9% (ActiGraph vs activPAL) to 81.9% (activPAL vs BAR). All pairs of instruments showed <75% agreement with the exception of walking as detected by activPAL versus BAR (79.1%) and sedentary behavior detected by activPAL versus BAR (81.9%) and by ActiGraph versus BAR (86.7%) for MVPA.

Similar trends were seen when using the κ statistic. The κ values showed moderate to high agreement in the sedentary behavior category ranging from 0.47 (by ActiGraph compared with activPAL) to 0.70 (by activPAL compared with BAR). There also were low to moderate κ values in the walking category ranging from 0.25 (by ActiGraph compared with activPAL) to 0.40 (by activPAL compared with BAR).

DISCUSSION

This study simultaneously compared subjective and objective measures used to assess multiple PA and sedentary

TABLE 3. Delta values for free-living behaviors in minutes monitored concurrently on a single day between pairs of instruments.

	Mean	SD	Range
Sedentary behavior			
activPAL − ActiGraph	−132.1	120.0	−582.3 to 2.8
activPAL − BAR	31.5	107.6	−170.0 to 310.3
ActiGraph − BAR	163.6	150.6	−57.3 to 542.5
Standing			
activPAL − BAR	49.0	168.8	−340.5 to 631.5
Walking			
activPAL − ActiGraph	−93.2	22.9	−148.0 to −39.8
activPAL − BAR	−65.0	136.7	−591.8 to 71.5
ActiGraph − BAR	28.1	139.5	−512.5 to 178.3
MVPA			
ActiGraph − BAR	−96.0	164.6	−749.0 to 35.5

ActiGraph does not have the capability of detecting time in standing behaviors specifically, and activPAL does not have the capability of detecting time in MVPA and, as such, is denoted as N/A.

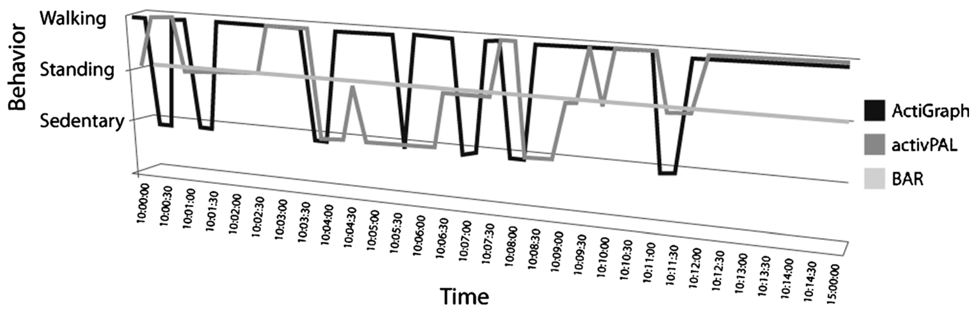

FIGURE 2—Example concurrent time interval for ActiGraph, activPAL, and BAR.

behaviors (in both a summary and a time interval analysis) as well as instruments that have the capability of detecting time in specific postures (e.g., sitting and standing) and movement (e.g., walking) in a free-living situation. For the summary data, both activPAL and BAR were able to detect similar amounts of time spent in walking and in sedentary behavior. In addition, activPAL and BAR showed moderate to high correlations for time spent in walking ($r = 0.53$) and sedentary behavior ($r = 0.87$), both of which were statistically significant at $P < 0.05$. On a time interval basis, activPAL and BAR also showed high agreement for walking (79.1%) and sedentary behavior (81.9%), which suggests that activPAL and BAR provide convergent data about most of the behavioral patterns (e.g., duration of sitting periods) studied, with the exception of standing. On the other hand, ActiGraph produced larger differences in minutes of walking and sedentary behavior compared with either activPAL or BAR.

The relatively divergent results of ActiGraph and activPAL for walking and sedentary behavior measures were surprising and bear further discussion. The results indicated ActiGraph consistently and significantly reported more time in walking and sedentary behavior than activPAL, and yet both instruments were worn concurrently. The activPAL offers three options when classifying behavior (i.e., sit/lie, standing, and walking), and its instrumentation is based on posture detection in combination with acceleration. In comparison, walking, MVPA and sedentary behavior are inferred from the ActiGraph by applying accepted activity count cut points. Given the similarities in acceleration detected between these instruments, the observed disagreement seems to be a function of the choice of ActiGraph cut points combined with the fact that there is no strategy for classifying standing behaviors separately from walking or sedentary behavior as detected by ActiGraph. The time interval analysis showed a low agreement between ActiGraph and activPAL ($r = 0.25$) for walking, which seems to contradict the high correlation ($r = 0.98$) of summary data between the two instruments. Similar to the summary analysis, the moderate agreement in sedentary behavior between activPAL and ActiGraph is likely a function of the cut point used in this study and the classification of standing behaviors by ActiGraph into either walking or sedentary behavior. Regardless of which cut point is used, the fact that activPAL detects posture (and therefore can discriminate standing) and ActiGraph can only differentiate sedentary behavior from walking by interpreting cut points based on intensity (not posture) will likely always lead to a discrepancy in these measured parameters between the instruments.

The BAR detected less time in sedentary behavior than both activPAL and ActiGraph. Matthews and Freedson (15) reported similar results when comparing a different accelerometer (TriTrac RT3) with BAR (753.7 $\text{min}\cdot\text{d}^{-1}$ by TriTrac vs 538.3 $\text{min}\cdot\text{d}^{-1}$ by BAR). On the basis of these studies, it seems that people self-report less time in sedentary behavior than is detected by ActiGraph and again likely due, at least in part, to the option to differentially report standing behaviors on the self-report measure. In contrast, the similarity in time detected in sedentary behavior between activPAL and BAR is likely due to the similar categorization of postures (e.g., sitting) by both instruments.

For summary time spent walking (i.e., all ambulation), ActiGraph detected more time for 100% of participants compared with activPAL (Δ ranging from -148.0 to -39.8 min). There was also evidence of systematic bias from the Bland–Altman plots of this comparison. These results were surprising because both activPAL (21) and ActiGraph (14) have been shown to be sensitive to walking at speeds as slow as 0.9 $\text{m}\cdot\text{s}^{-1}$. Comparatively, BAR consistently detected more time in walking for 59.4% of participants versus ActiGraph. These results agree with the findings in the Matthews and Freedson (15) study, which compared an accelerometer (TriTrac) with BAR and reported that BAR estimated more time in walking than the accelerometer (78.0 vs

TABLE 4. Mean percent agreement and κ statistics for the time interval analysis of all free-living behaviors between pairs of instruments.

	Sedentary Behavior	Standing	Walking	MVPA
% Agreement				
ActiGraph vs activPAL	64.9	N/A	54.0	N/A
ActiGraph vs BAR	67.2	N/A	58.9	86.7
activPAL vs BAR	81.9	74.0	79.1	N/A
κ				
ActiGraph vs activPAL	0.47	N/A	0.25	N/A
ActiGraph vs BAR	0.51	N/A	0.35	0.41
activPAL vs BAR	0.70	0.31	0.40	N/A

ActiGraph does not have the capability of detecting time in standing behaviors specifically, and activPAL does not have the capability of detecting time in MVPA and, as such, is denoted as N/A.

37.5 min·d^{-1}). In the present study, group means for time spent in walking as detected by both activPAL and BAR were the same, and individuals held their rank order between these instruments to a moderate extent. The high level of agreement in the time interval analysis would suggest that both instruments are appropriate for the examination of patterns in walking and that the majority of these behaviors can be captured in specified time intervals throughout the day (e.g., 15 min).

The comparison between ActiGraph and BAR measures of MVPA, a subcomponent of walking, showed a weak and nonsignificant correlation (r = 0.22), which was consistent with the findings from a previous study (22), which showed a very similar correlation (r = 0.23). The time interval agreement for MVPA between the ActiGraph and BAR was high (86.7%). However, inspection of individual participants' data for this analysis showed that most of the MVPA time intervals were misclassified as walking (i.e., >100 counts per minute) by ActiGraph. In fact, >10% of self-reported MVPA time intervals were detected as a lower intensity by ActiGraph, providing further evidence of misclassification.

This study was not without limitations. As mentioned previously, at this time, activPAL does not have the capability to differentiate intensities of walking. It does, however, detect cadences, and it requires future identification of appropriate cut points to infer intensity from these, much like what is already done with ActiGraph. ActiGraph does not have the capability of detecting postures (specifically sitting and standing) and only estimates time spent in different intensities (e.g., sedentary behavior and light, moderate, and vigorous PA). These two instrument limitations made it so that MVPA could not be evaluated in activPAL or standing in the ActiGraph. In the time interval analysis, data from the accelerometers were extended from the original epoch length (15 s) to those of the BAR (15 min). As a result, there was the potential for data "smoothing" or for certain activities to be absorbed into the primary activity. For example, this could occur when classifying the time interval as the primary activity (e.g., sedentary behavior) when other activities may have also occurred in that 15-min period (e.g., walking). In addition, this study was not designed to make conclusions about habitual behavior performed under free-living conditions but rather to test the assembled instruments' unique abilities to detect them. Participants were fairly homogenous; all were self-identified runners from a suburban community. The mean age of these runners was 30 yr old; the youngest was 20 yr, and the oldest was 51 yr. Results from this study are therefore only applicable when using the instruments in similar populations. Finally, there was no true criterion measure, so we are unable to make conclusions about relative accuracy of these instruments and their actual abilities to detect sedentary behaviors, standing, walking, or MVPA.

In summary, this study examined the convergent validity of subjective and objective measures of multiple PA and sedentary behaviors on a summary level and on a time interval level. The activPAL and BAR showed convergence in detecting walking and sedentary behavior on both levels. The discordance between activPAL and ActiGraph was likely a function of the differential definitions/cut points used to distinguish sedentary behavior from higher orders of PA. In addition, the high agreement between activPAL and BAR in sedentary behavior and walking on a summary and time interval level suggests that both of these instruments are appropriate for use in free-living assessment and will give similar results. Specifically, the self-report measure seems to be reasonable for studies of sitting and lying time if the outputs need to be compared with those of activPAL. The first, an objective instrument (activPAL) has been proven to be an accurate measure of both PA and sedentary behavior, but the high cost limits its use. Alternatively, a subjective measure (BAR) has shown high agreement with activPAL and can be administered for a fraction of the cost. Having these instruments with similar abilities to measure both walking and sedentary behavior will provide researchers with options for examining associations between these behaviors and health-related outcomes.

The authors have no financial or other interests in the products, manufacturers, or distributors of the products evaluated and have no conflicting interests related to the article.

The results of the present study do not constitute endorsement by the American College of Sports Medicine.

The current study was conducted as a part of the first author's doctoral program completed at Arizona State University.

EPIDEMIOLOGY

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