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Validation of a physical activity accelerometer device worn on the hip and wrist against polysomnography

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ABSTRACT

Study purpose: The integration of methods to assess daytime physical activity (PA) and sedentary behavior (SB) and nighttime sleep would allow the evaluation of 24-hour daily activity using a single device. Accelerometer devices used to assess daytime PA have not been substantially validated to evaluate sleep. The objective of this study was to use polysomnography (PSG) to validate a commonly used PA accelerometer worn on both wrists and the hip.

Methods: Seventeen participants (50-75 years) completed a single-night in-home PSG recording while concurrently wearing 3 PA accelerometers. Accelerometer devices were worn on each wrist and the hip. Total sleep time (TST), sleep efficiency (SE), and wake after sleep onset (WASO) were compared for each device against PSG. Correlation coefficients estimated measurement agreement. Paired *t* tests and Bland-Altman plots assessed measurement differences.

Results: Between PSG and devices, mean TST ranged from 361.6 to 403.2 minutes. Mean SE estimates ranged from 86.9% to 96.9%. Mean WASO estimates ranged from 12 to 51.2 minutes. For TST, SE, and WASO hip estimates differed significantly from PSG estimates (paired *t* tests, TST: $P = .03$, SE: $P < .001$, WASO: $P < .001$). No significant differences were found between wrist accelerometers and PSG estimates of TST, SE, or WASO.

Conclusions: PA accelerometer devices worn on either wrist provide valid estimates of TST, WASO, and SE when compared with PSG. Further studies are needed to investigate methods to improve assessment of sleep parameters by PA accelerometer devices to advance device integration and assessment 24-hour activity in populations.

Introduction

In older adults, poor sleep has been associated with cardiovascular events (eg, stroke), depression, obesity, insulin resistance, and mortality.[1–6] Given the relationship between poor sleep and poor health outcomes, a need for simple and valid sleep measurement is apparent. Full polysomnography (PSG) accurately characterizes sleep architecture and is considered the current clinical "gold standard" for sleep assessment.[7] Unfortunately, PSG may be burdensome for the participant, expensive, and limited for use outside of the clinic setting.[8] Despite frequent use in population-based studies, self-report sleep assessments often overestimate total sleep time and poorly capture some aspects of sleep quality and fragmentation.[9,10] Because of the relationship between sleep and health, and the growing need for the assessment of sleep in population studies and community-based interventions, research efforts are needed to validate the use of popular physical activity (PA) accelerometer devices for the objective assessment of sleep.

Actigraphy devices worn on the wrist were first used for the assessment of sleep in 1972.[11,12] Devices, algorithms, and guidelines for the clinical use of actigraphs for measuring sleep were developed completely separately from parallel work in physical activity

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research. Among physical activity researchers, actigraphy has grown in popularity for the measurement of daytime PA and sedentary behavior (SB) in population studies. PA and SB have traditionally been measured by accelerometers worn on the hip during waking hours only.[13,14]

The integration of methods to assess daytime PA and SB, and night time sleep would allow the evaluation of 24-hour daily activity using a single device.[15] More recently, PA researchers have explored this integration of methods with 24-hour protocols for both hip and wrist devices not only to assess all daily behaviors with one device but also to improve wear-time compliance with devices.[16] Controversy remains regarding wrist-worn vs hip-worn accelerometers to assess sleep and PA due to patient preferences, questions around validation, and adherence with the devices.[17–19] Additionally, questions remain over whether wrist-worn devices should be worn on the dominant vs nondominant hand.[17]

Comprehensive reviews suggest that sleep-wake scoring algorithms are likely to be specific to each accelerometer device and wear location due to differences in how acceleration data are filtered, postprocessed, and aggregated into epochs.[7,20] Existing algorithms developed for sleep accelerometers on the wrist may not perform as well when applied to PA accelerometer data, especially when worn on the hip location. To date, devices being used to assess daytime PA have not been substantially validated to evaluate sleep. It is important to apply existing sleep algorithms to PA accelerometers, worn on the hip and both wrists, to examine the validity of their use for sleep assessment beyond their use for PA assessment.

The objective of this study was to validate the GT3X+ (ActiGraph, LLC, Pensacola, FL), a commonly used PA accelerometer device, for sleep assessment when worn on the hip, dominant wrist, and nondominant wrist. The primary aim was to compare the assessment of total sleep time (TST), sleep efficiency (SE), and wake after sleep onset (WASO) by 2 wrist-worn GT3X+ accelerometers (nondominant is the default for sleep research) and a hip-worn GT3X+ accelerometer (default for PA research). In-home PSG was used as the standard comparison. Additionally, 2 different sleep-scoring methods were used (sleep interval defined with sleep diaries and with an activity count cut point) to explore existing in-bed/out-of-bed protocols. The objective of this study was to answer the research question: do the GT3X+ PA accelerometer devices worn on the hip, dominant wrist, and nondominant wrist differ significantly from PSG in assessments of TST, SE, and WASO?

Methods

Study sample and study design

Community-dwelling adults were recruited from the San Diego community and from The UCSD Airway Research & Clinical Trials Center to participate in a pilot study to inform a population-based study investigating sleep disturbances in patients with chronic conditions. To be eligible, adults had to be between 50 and 75 years of age, be willing to wear 3 accelerometers, undergo a 1-night unattended full in-home PSG monitoring session, and be willing to complete a survey packet. Potential study participants were screened for sleep disturbances using the Epworth Sleepiness Scale[21] and impaired health using a brief interview. Individuals were excluded if they had a body mass index (BMI) >30 kg/m^2, had poor self-reported health, had been previously diagnosed with a sleep disorder (eg, insomnia), or were currently taking medications that could disrupt sleep. A portion of the sample intentionally included individuals previously diagnosed with respiratory conditions related to disordered sleep including asthma or chronic obstructive pulmonary disease (COPD). These efforts were made to recruit adults who may or may not experience disturbed sleep, including those who may experience sleep disordered breathing but may be undiagnosed, to create a sample that was representative of the general middle-aged to older adult population. The study protocol was approved by the institutional review board at the UCSD. The study was conducted between May 2011 and January 2012.

Data collection

Participants were scheduled for a baseline visit at UCSD clinical trials center. Trained staff obtained written informed consent and reviewed study procedures with the participant. Participants were scheduled to complete a single overnight in-home PSG monitoring session and to wear GT3X+ accelerometer devices on the hip and both wrists concurrently. All in-home data collection took place on weeknights. Participants were instructed to go to bed as close to their regular bedtime as possible and were encouraged to engage in their regular prebedtime behaviors. Prior to falling asleep, participants were asked to blink 10 times to signify the initiation of sleep. Additionally, participants were asked to complete a sleep diary and record: (1) time in bed; (2) lights out; (3) lights on, and (4) time out of bed in the morning. Study staff collected the equipment in the morning at the participants' usual wake time, and equipment was taken back to the sleep laboratory where data were downloaded for analysis.

Measures

The standardized outcome measurements to be used for validation were TST, SE, and WASO.

Somte in-home polysomnography monitor (Compumedics: Abbotsford, Australia)

A single night of PSG sleep data was collected using an in-home PSG monitor in the participant's home. The Somte PSG monitoring device measures 2 electroencephalogram channels (C4, O2), 2 electroculogram channels (REOG, LEOG), a chin electromyogram channel, an electrocardiogram channel, bilateral tibialis anterior EMG, snoring, air flow by a nasal-oral thermocouple and nasal pressure recording, thoracic and abdominal respiratory effort (using piezoelectric bands around the thorax and abdomen), body position, and pulse (finger oximetry). Data were downloaded and scored by a blinded, registered polysomnographic technician using Compumedics ProFusion PSG 3 V3.4 software following the American Academy of Sleep Medicine guidelines.[22] Sleep was staged in 30-second epochs, and the *in-bed sleep interval* was defined as the time from the reported in bed and lights off and the 10 repeated blinks to morning lights on. Sleep diary data were used to support PSG analysis. During the monitoring session, after lights were turned off, participants were instructed to blink 10 times prior to falling asleep, serving as a signal in the data for the trained technician to determine the start of the sleep interval. TST was calculated as the total duration of 30-second epochs scored as sleep during this in-bed sleep interval. SE was calculated as the percentage of epochs that were scored as sleep during the in-bed sleep interval. WASO was calculated as the total minutes of wake during the in-bed sleep interval after sleep onset.

GT3X+ accelerometer devices (ActiGraph)

PA accelerometer device sleep was measured using 3 GT3X+ accelerometers. The GT3X+ is a lightweight (19 g) triaxial accelerometer with 512 MB of nonvolatile flash memory, a dynamic range of ±6 g, and a user-specified sampling rate of 30-100 Hz. Each participant wore 3 GT3X+ accelerometer devices during the night, one on the nondominant wrist, one on the dominant wrist, and one on the hip. Raw GT3X+ data (30 Hz) were band-pass filtered with the Low-

Frequency Extension option enabled. The vector magnitudes of the x, y, and z axes were digitally integrated and reported as a single "count" across 60-second epochs. All GT3X+ accelerometer device data were processed and scored by trained staff using ActiLife v6.11 software. To test 2 different sleep actigraphy data processing techniques, the sleep interval was defined using 2 different approaches for the wrist-worn devices: (1) An activity count cut point of 1000 counts was used to define the start (first minute of 0 count after drop from 1000 counts) and end (first minute before increase from 0 count over 1000 counts) of the sleep/wake interval and (2) a sleep diary, where the participant logged reported lights off and lights on. For the hip-worn devices, the sleep interval was only defined using the sleep diary method. The activity count cut point approach was developed using wrist-worn devices and is not an appropriate cut point for hip-worn devices due to the difference in count magnitude. Lastly, the Cole-Kripke algorithm[23] was applied to defined sleep intervals to determine TST and SE. TST was derived as the total number of minutes categorized as "sleep" during the defined sleep interval. SE was calculated as the percentage of the in-bed sleep interval that was scored as sleep. WASO was calculated as the total minutes of wake during the in-bed sleep interval after sleep onset.

Data analysis

TST, SE, and WASO were calculated for each GT3X+ accelerometer device and PSG according to study protocol. The difference between the sleep estimates as assessed by each GT3X+ accelerometer and PSG were examined using paired *t* tests. Measurement agreement between each of the GT3X+ accelerometer devices and PSG was evaluated with Spearman and Pearson correlations.

Bland-Altman method[24] was used to assess measurement differences, including the plotting of the differences against the measure mean. These plots allow the difference between the measurement methods to be visualized and also allows for the investigation of patterns in measurement error.[24] Bland-Altman plots were created to assess the pattern and magnitude of differences in sleep parameter estimates between each GT3X+ accelerometer device and standard PSG. The comparative validity of each GT3X+ accelerometer device for predicting PSG-measured sleep parameters was determined by comparing the mean difference in TST, SE, and WASO between the hip and wrist GT3X+ accelerometer to PSG. To visualize systematic differences in the sleep characterization of the GT3X+ accelerometer devices between healthy individuals (nondiseased) and those participants classified as having a sleep-related respiratory condition, the 2 groups were plotted separately. For the wrist-worn accelerometer devices, analyses were performed using both the activity count cut point–defined and sleep diary–defined sleep intervals. R statistical software version 3.1.1[25] was used for analyses.

Of note, previous validation studies of accelerometers against PSG typically examined epoch-by-epoch differences to compute rate of agreement, percent agreement on sleep epochs, and percent agreement on wake epochs.[26] For this study, an epoch by epoch approach was not taken and was not possible to perform with reliability. The accelerometer and PSG clocks were not exactly synchronized, precluding the ability to line up epochs accurately and complete an epoch-by-epoch analysis. Without time syncing, the rate of agreement between epochs cannot be reliably established, and therefore, the performance of the device and algorithm cannot be evaluated in this way. Furthermore, the PSG and accelerometer devices sampled data at different epoch lengths, making the matching of epochs difficult. In clinical practice, actigraphy is used by averaging sleep windows rather than analyzing every epoch as we do for PSG. Thus, this study will evaluate systematic differences in the clinical performance of each of the 3 accelerometer devices as compared with polysomnography.

Results

Study participants

Participant demographics are presented in Table 1. Prior to analysis, 5 participants were excluded from the recruited sample of 22 participants because they did not meet the inclusion criteria or had incomplete data. Seventeen study participants completed the full in-home PSG session and questionnaires and were included in the final analysis. The mean age of participants was approximately 58 years (SD = 7.0), and 58.8% of the sample was female. Non-Hispanic whites were 88.2%, and 11.7% were Hispanic/Latinos of the study sample. The mean BMI of participants was 24.67 kg/m^2 (SD = 4.4). Four of the participating study participants (23%) had been previously diagnosed with one or more respiratory conditions related to disordered sleep including asthma or COPD.

GT3X+ accelerometer device estimates of TST and SE

Table 2 provides a summary of TST, SE, and WASO estimates for the 3 GT3X+ accelerometer devices used in this study. Estimates of mean TST varied across GT3X+ accelerometer devices, ranging from 6.02 hours (dominant wrist-worn accelerometer) to 6.7 hours (hip-worn accelerometer). SE estimates also varied across GT3X+ accelerometer devices, ranging from 87.2% estimated by the dominant wrist-worn accelerometer to 96.9% estimated by the hip-worn accelerometer. SE estimated by PSG (86.9%, SD 7%) was lower than that of all of the accelerometer devices. Across participants, the mean WASO estimated by PSG was 49 minutes. WASO estimates varied across wrist-worn devices with mean WASO ranging from 51.2 to 40.1 minutes and appeared to be underestimated by the hip-worn device with a mean of 12 minutes. Moderate agreement (determined a priori to be 0.60) determined by Spearman correlations was found between each of the devices and PSG for TST. Hip-worn accelerometers had the strongest correlation to PSG assessed TST ($r = 0.73$). For SE, there was mostly poor agreement for each device compared with PSG ($r = 0.13$-0.54). We also examined concordance between accelerometer device–measured sleep and PSG using Pearson correlation coefficients, and the results were not materially different than those found using Spearman correlations (data not shown). Paired *t* tests were used to examine differences in mean estimates of TST, SE, and WASO. We did not find a significant difference between TST assessed by PSG and TST assessed by wrist accelerometer devices worn on either wrist (dominant wrist with sleep diary $P = .63$, dominant wrist with activity count cut point $P = .93$, nondominant wrist with sleep diary $P = .94$, nondominant wrist with activity count cut point $P = .49$). However, there was a significant difference between TST assessed by hip-worn accelerometer devices and PSG-assessed TST ($P = .03$). Regarding SE, we found similar results, with a nonsignificant difference between SE assessed by wrist-worn accelerometer devices (dominant wrist with sleep diary $P = .87$, dominant wrist with activity count cut point $P = .99$, nondominant wrist with sleep diary $P = .28$, nondominant wrist with activity count cut point $P =$

Table 1
Sleep actigraphy validation participant characteristics, N = 17

Demographics	n (%)
Age, mean (SD)	58.47 (7.0)
Sex	
Female	10 (58.8%)
Race/ethnicity	
White	15 (88.2%)
Hispanic	2 (11.7%)
BMI, mean (SD)	24.67 (4.4)
Preexisting sleep-related respiratory conditions (asthma & COPD)	4 (23.5%)

Table 2
Summary sleep measures for 17 participants in sleep actigraphy validation

Measure	TST in min, mean (SD)	SE, mean % (SD)	WASO in min, mean (SD)
PSG	365.3 (76.9)	86.9 (7.0)	49 (35.6)
Dominant wrist with sleep diaries	361.6 (67.4)	87.2 (7.2)	51.2 (33.2)
Nondominant wrist with sleep diaries	371.6 (68.4)	89.5 (6.0)	41.8 (28.9)
Dominant wrist	362.3 (70.0)	88.5 (6.0)	43.4 (25.1)
Nondominant wrist	373.7 (63.1)	89.3 (5.7)	40.1 (25.4)
Hip	403.2 (72.0)	96.9 (1.9)	12 (9.3)

.47). Similar to the results for TST, there was a significant difference between hip-worn SE and PSG ($P < .001$). Paired t test results for WASO were similar to those for TST and SE. There was no significant difference found between PSG estimates and wrist-worn devices estimates; however, a significant difference was found between PSG-estimated WASO and hip-worn device estimated WASO ($P < .001$).

Bland-Altman plots for the dominant and nondominant wrist accelerometer device estimates of TST and SE are shown in Figs. 1-3 (hip plot not included). Corresponding Bland-Altman statistics (including the hip) are shown in Table 3. The Bland-Altman plots and corresponding statistics demonstrate the pattern of the differences between each GT3X+ accelerometer device and PSG. The mean difference in TST for the nondominant wrist was an underestimate of 6.28 minutes, and that for the dominant wrist was an overestimation of 3.78 minutes (sleep diary–defined sleep interval). Fig. 1 is a Bland-Altman plot showing the pattern of distribution of participant TST estimates assessed by the wrist-worn GT3X+ accelerometer devices compared with PSG. The plots demonstrate that 35% of TST estimates from the nondominant wrist-worn devices (sleep diary defined sleep interval) fall within 15 minutes of the mean PSG TST estimates. The mean difference in TST duration in minutes for the hip-worn accelerometer device was an underestimation of 37.8 minutes.

The mean difference in SE assessed by wrist-worn devices and PSG methods ranged from −2.60% to −0.29%. The smallest difference in mean SE estimates was observed between the PSG and the dominant wrist-worn accelerometer device (activity count cut point–defined sleep interval). A priori 5% difference was deemed a clinically significant in SE. Fig. 2 is a Bland-Altman plot showing the pattern of distribution of participant SE estimates assessed by the nondominant wrist-worn GT3X+ accelerometer devices (activity count cut point–defined sleep interval) compared with PSG. The pattern of SE estimates shows that 57% of SE estimates from the nondominant wrist-worn accelerometer devices (activity count cut point–defined sleep interval) fall within 5% of the mean PSG SE estimates. There was no significant difference between wrist-worn accelerometer device estimates of SE and PSG estimates of SE (5% error tolerance represented by the dotted lines). The mean difference in the estimate of SE assessed by the hip-worn accelerometer device was an underestimation of 10.03%, a clinically-significant underestimation of SE ($P < .001$) (plot not shown). The mean difference in WASO assessed by wrist-worn devices and PSG methods ranged from −2.17 minutes

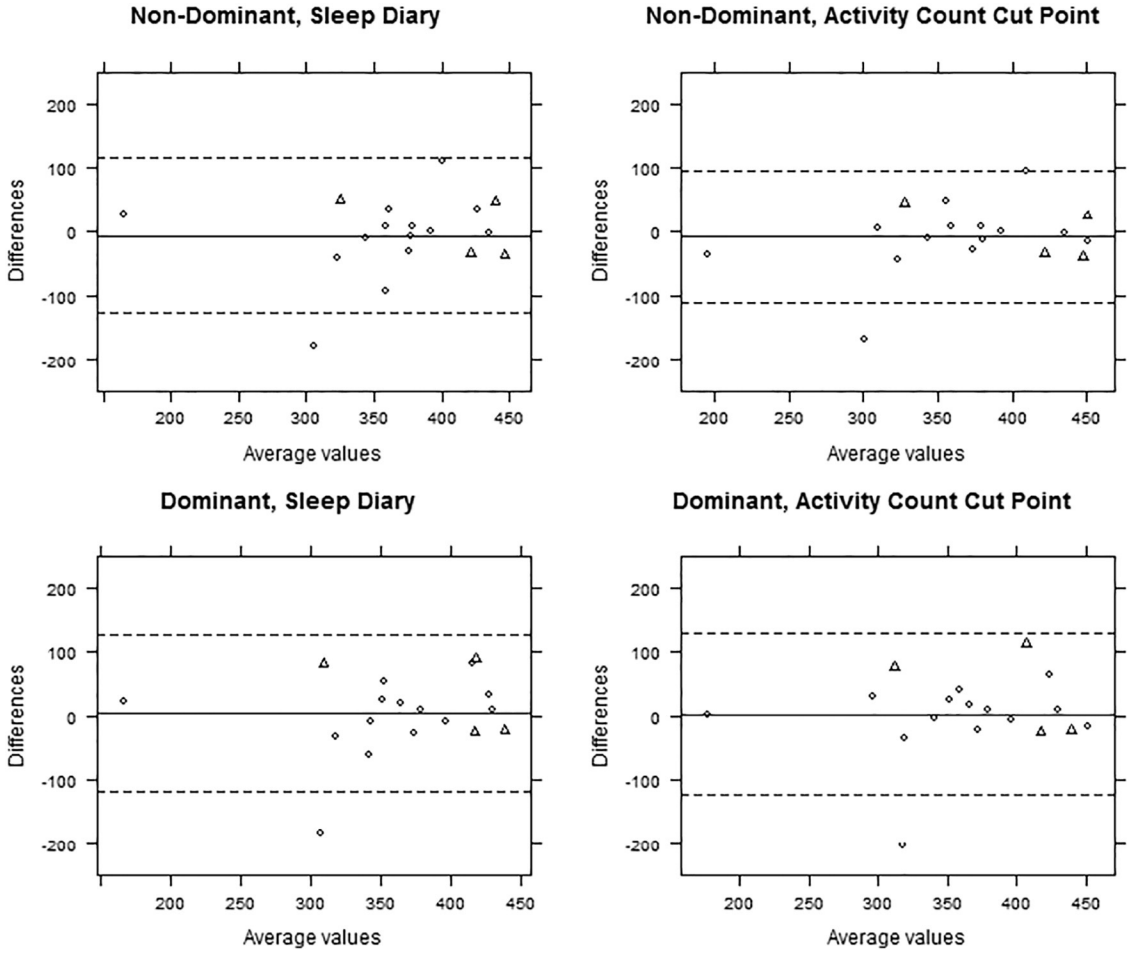

Fig. 1. Bland-Altman plots of TST of wrist actigraphy vs PSG. Circle: healthy participants; Triangle: participants with sleep-related respiratory conditions; Solid line: mean difference; Dash line: 95 confidence interval; Dot line: 5% error tolerance (sleep efficiency only).

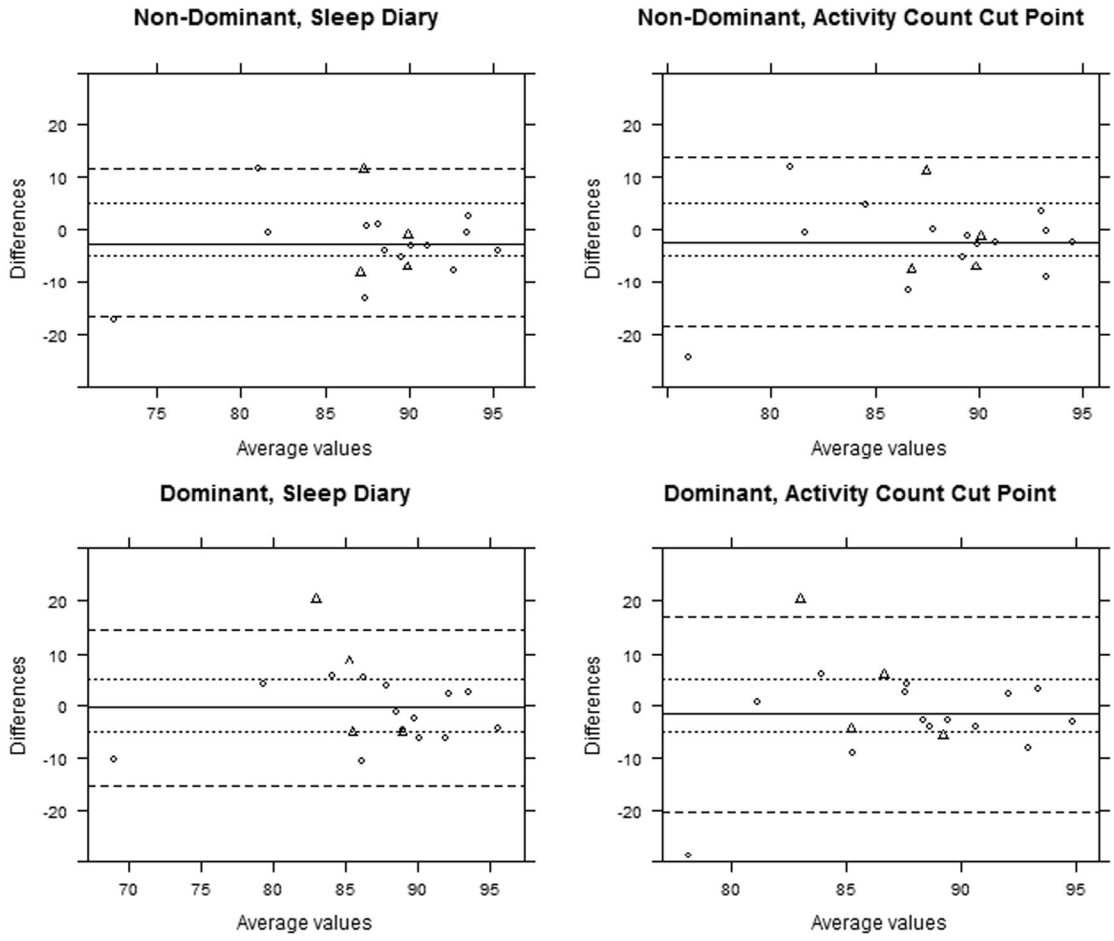

Fig. 2. Bland-Altman plots of SE of wrist actigraphy vs PSG. Circle: healthy participants; Triangle: participants with sleep-related respiratory conditions; Solid line: mean difference; Dash line: 95 confidence interval; Dot line: 5% error tolerance (sleep efficiency only).

estimated by the dominant wrist (sleep diary method) and 8.89 minutes estimated by the nondominant wrist (activity count cut point–defined sleep interval). The smallest difference between PSG estimates and accelerometer devices estimates in mean WASO was observed between the PSG and the dominant wrist-worn accelerometer device (activity count cut point–defined sleep interval). Across all 3 sleep parameters, the dominant wrist-worn accelerometer device (activity count cut point–defined sleep interval) appeared to have the closest estimates to PSG estimates. The mean difference in WASO in minutes for the hip-worn accelerometer device was an overestimation of 37 minutes.

The Bland-Altman plots in Figs. 1 and 2 demonstrate that across the wrist-worn accelerometer devices, for TST and SE, neither a slope nor pattern in estimate variations is observed, meaning there is no apparent systematic trend in the bias of the accelerometer device estimates when compared with PSG. Similar patterns were observed for WASO (Fig. 3). Further, when comparing the assessment of sleep in healthy participants versus participants with sleep-related respiratory conditions, there was no pattern found in the bias of measures between groups.

Discussion

This study aimed to contribute to existing sleep literature and research on activity behavior assessment by validating a commonly used PA GT3X+ accelerometer device worn on the hip and each wrist for the assessment of TST, SE, and WASO against PSG. Despite the growing popularity of actigraphy sleep assessment,[8] studies examining the validity of PA accelerometer devices compared with PSG are scarce. Furthermore, beyond the complexity of in-field sleep assessment, these studies and their results have been limited by the devices selected for validation, participant compliance, and inadequate device algorithms.[20] GT3X+ accelerometer devices may be used to collect measures of sleep in population studies or community-based interventions and provide valuable information to clinicians[8]; however, research studies are needed to confirm if these devices provide valid assessments of TST, SE, and WASO. Sleep duration and quality have been associated with important cardiometabolic complications, making the accurate objective assessment of sleep important to both clinicians and community health researchers. Many sleep clinicians rely on traditional techniques (PSG and participant sleep diaries) to treat and diagnose patients; however, objective assessment of sleep behaviors, in addition to PA behavior, outside of the clinic setting is limited and would provide a complementary tool for diagnosis and treatment.[8] When proven valid, accurate assessments of TST, SE, and WASO collected outside of the clinic setting can help clinicians diagnose circadian rhythm sleep disorder, sleep deprivation, and other sleep disorders.[27] Additionally, valid sleep assessments may significantly contribute to the estimation of the risk of cardiometabolic conditions in large population studies where PA accelerometer devices are currently being used.[28–30]

Our study results comparing hip-worn GT3X+ accelerometer and wrist-worn GT3X+ accelerometer devices to PSG are consistent with previous study findings. Zinkhan et al found that wrist-worn SOMNOwatch accelerometers performed better in assessing TST

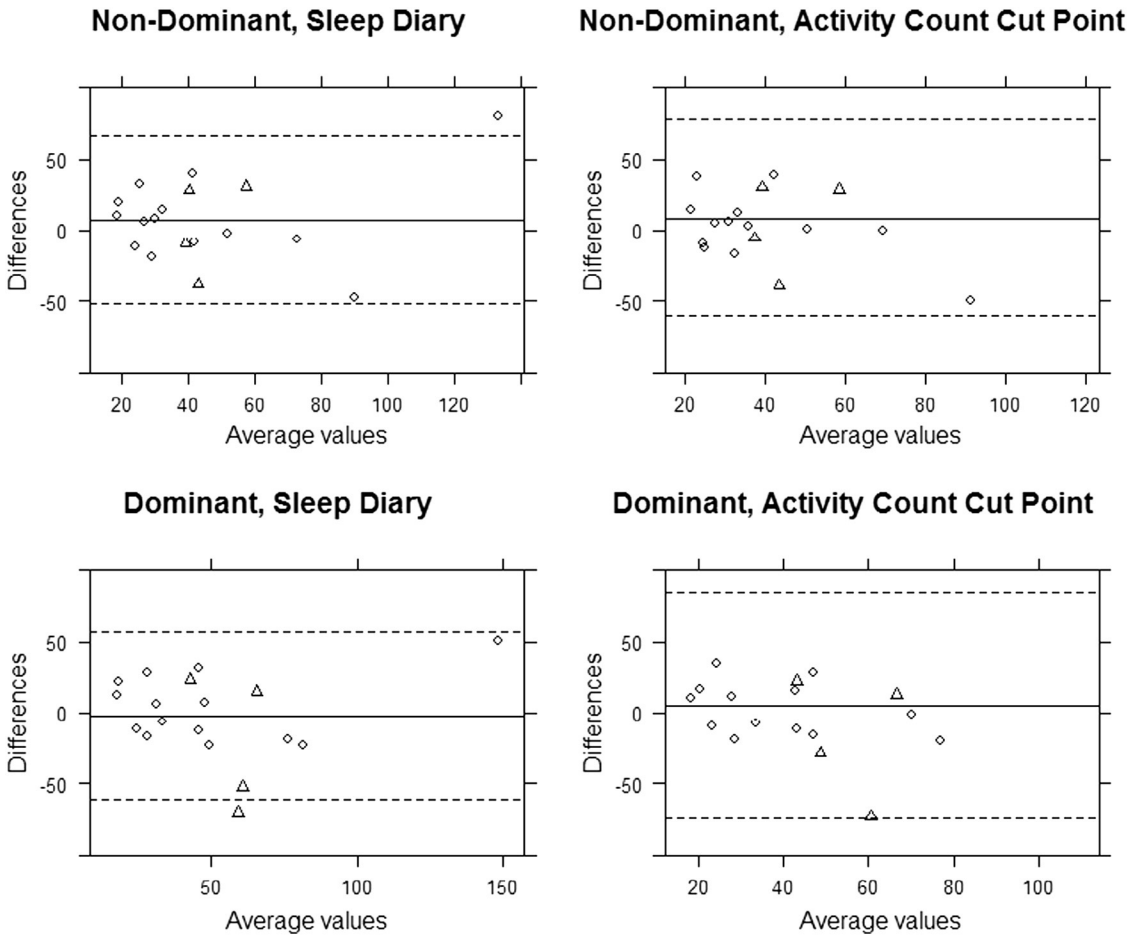

Fig. 3. Bland-Altman plots of WASO of wrist actigraphy vs PSG. Circle: healthy participants; Triangle: participants with sleep-related respiratory conditions; Solid line: mean difference; Dash line: 95 confidence interval.

and SE parameters than the GT3X+ hip-worn accelerometers when compared with PSG.[19] Similarly, our study results demonstrate that TST, SE, and WASO results from both the dominant and nondominant wrist-worn GT3X+ accelerometer devices did not differ significantly from the PSG results. Our analyses further demonstrate that hip-worn GT3X+ accelerometer device results significantly differed from PSG results for TST, SE, and WASO. Differing from the Zinkhan et al study, this study used the same GT3X+ accelerometer device on the hip and both wrists, a device commonly used to assess PA, and not a device originally developed to assess sleep. In a validation study of 3 accelerometer devices, 2 developed for sleep (Actiwatch and Sleepwatch) and 1 for PA (Actical) among 30 adolescents, Weiss et al found that the sleep-developed wrist devices performed better at assessing both SE and TST. However, the PA accelerometer, worn on the wrist, did provide a valid assessment of TST.[31]

The findings for the poorer performance of the hip-worn GT3X+ accelerometer device to assess sleep are important for PA researchers. In weighing hip or wrist placement for PA and SB, researchers are currently still more likely to use the hip location because of superior performance for measuring PA,[17] especially if worn on the hips for 24 hours, improving wear-time compliance. If researchers also now consider the poorer performance of the hips for measuring dimensions of sleep besides TST, they may decide that a wrist placement is overall more accurate.

This study was one of the first studies of its kind to examine the GT3X+, a PA accelerometer device, for the assessments of sleep with devices worn on both the dominant and nondominant wrist. Although it is commonly accepted by sleep researchers for the accelerometer device to be worn on the nondominant wrist, there is limited evidence to support that one wrist provides more accurate assessment than the other.[7] We did not find a significant difference between either of the wrist-worn GT3X+ accelerometer devices (dominant or nondominant hand) from our PSG results. Our results demonstrate that the GT3X+ accelerometer devices can be used on either wrist for comparable assessments of TST and SE. Furthermore, across all 3 sleep parameters, the dominant wrist-worn

Table 3
Bland-Altman statistics for differences between actigraphy and PSG estimates of TST, SE, and WASO

	TST mean difference in min (SD)	SE mean difference percentage (SD)	WASO mean difference in min (SD)
Dominant wrist (with sleep diaries)	3.78 (62.16)	-0.29 (7.58)	−2.17 (30.19)
Nondominant wrist (with sleep diaries)	−6.28 (61.63)	−2.60 (7.19)	7.22 (30)
Dominant wrist (activity count cut point)	3 (64.11)	−1.59 (9.53)	5.61 (40.34)
Nondominant wrist (activity count cut point)	−8.39 (52.49)	−2.42 (8.27)	8.89 (35.27)
Hip-worn (with sleep diaries)	−37.83* (61.27)	−10.03* (6.40)	37* (30.73)

accelerometer device (activity count cut point–defined sleep interval) appeared to have the closest estimates to PSG estimates. Previous evidence has been inconclusive on which wrist placement provides the most accurate measurement of 24-hour activity. Many PA studies, including the National Health and Nutrition Examination Survey of objective PA data, using wrist-worn accelerometers have adopted the practice of placing the device on the nondominant wrist.[32] Furthermore, previous sleep actigraphy validation studies have placed the accelerometer on the nondominant wrist.[17] Only 1 study has assessed the dominant hand for SB behavior.[18] If wrist placement does not matter for sleep assessment, PA researchers might now be more inclined to also assess wrist placement in PA research. Given the new algorithms that recognize accelerometer signal patterns, it seems reasonable that algorithms could be trained to recognize movement on either wrist. There may be some PA activities that are underestimated if the nondominant wrist-worn device only is used. Clearly, more research is needed into the accelerometer devices used, algorithms applied, and activity being measured. This study contributes to the evidence base demonstrating that for sleep assessment, accelerometer devices worn on either the dominant or nondominant wrist provide comparable estimates of TST, SE, and WASO.

When compared with SE and WASO, both hip- and wrist-worn GT3X+ accelerometer devices provided more accurate assessments of TST in our analysis. We believe that the more accurate results of TST may be due to the analysis techniques used to define the sleep interval. To our knowledge, this was the first actigraphy validation study to include a comparison of different approaches to defining the sleep interval. In our study, we explored defining the sleep interval using 2 different methods: an activity count cut point of 1000 counts per 60 seconds on the x-axis and a sleep diary completed by the study participant. Society of Behavioral Sleep Medicine guidelines recommend an activity count threshold to identify a sharp decrease and increase in activity to define the sleep interval; previous sleep researchers have used a threshold of 1000 counts per 60 seconds.[7] We used both the 1000-count and sleep diary methods to define manually the sleep interval in our analysis. Our analysis demonstrated mixed results in determining which method provided a more valid assessment of TST, SE, and WASO. Several studies of accelerometry compared with sleep diaries have concluded that accelerometers can replace sleep diaries, but no PSG was used for evaluation in these studies, and therefore, authors suggested caution in interpreting the findings.[15] Our results are inconclusive in determining which method is more accurate for defining the sleep interval.

As mentioned, previous validation studies of this kind have typically examined epoch-by-epoch differences to compute rate of agreement, percent agreement on sleep epochs, and percent agreement on wake epochs.[26] For this study, we did not use an epoch-by-epoch approach because it did not match with the data available. Clinically, we typically use actigraphy with averaging windows rather than analyzing every epoch as we do for PSG. Thus, the goal of this study was to evaluate systematic differences in the clinical performance of each of the 3 accelerometer devices as compared with polysomnography. The methods used in this study are commonly used to validate new clinical methods that purport to approximate existing methods,[24] and not only are sufficient to determine whether the accelerometer estimates sleep with some accuracy compared with PSG but, more importantly, provide information on the relative performance of the accelerometers placed on wrists vs on the hip.

We acknowledge that our study has some limitations. First, the sample size assessed was smaller than proposed, resulting in a study with weak power, making it difficult to reject the null hypothesis. This study was intended to be a small feasibility pilot study, and therefore, recruitment efforts were not expanded. Efforts were made to recruit both healthy individuals and individuals who may be currently experiencing undiagnosed disordered sleep to acquire a sample more representative of the general population. Although this sample was intended to be representative, the small sample size limited our ability to conduct comparative analyses of the 2 groups. The Bland-Altman plots in this analysis suggest differences in the assessment of the healthy individuals and the group with possible disordered sleep; therefore, future studies may be warranted. Second, because of the comparison of several accelerometer device placements in this study (including 3 devices and PSG), as well as the different approaches to defining the sleep interval, we focused our assessment on just 3 dimensions of sleep—TST, SE, and WASO—and did not include other possible sleep variables, such as sleep latency or number of awakenings. Third, because we collected data in 1 single night and because of known night-to-night variability in sleep patterns, the sleep pattern assessed may not be reflective of a participant's normal night of sleep due to difficulty of sleeping with 3 devices and a PSG monitor. Additionally, we acknowledge that the difference in epoch sampling rates between PSG and accelerometer devices (60 vs 30 seconds) may introduce bias into data sampling. Postsampling attempts to expand or collapse these epoch windows may result in estimate errors. Lastly, our study population was recruited from a sample of middle-aged and older adults. We focused on adults between the ages of 50 and 75 years old because there are a high presence of multiple comorbid conditions, low levels of physical activity, and increased reports of sleep problems in this age.[33–35] Having a single device to measure PA, SB, and sleep objectively in this population may improve the design of lifestyle interventions to address these conditions. Although this sample selection was intentional, we do acknowledge that this narrow age range does limit generalizability of our findings to sleep assessments in younger or older adults. One strength of this study is that we included both healthy individuals and individuals with previously diagnosed respiratory condition related to disordered sleep including asthma and COPD, strengthening the generalizability of the sample assessed.

In conclusion, this study demonstrates that the GT3X+ accelerometer device, worn on either wrist, provides acceptable estimates of TST, SE, and WASO and may be used in clinical practice to characterize sleep behavior. Future validations studies of PA accelerometer devices worn on the wrist are needed to confirm if devices with this placement can accurately characterize daytime activity behaviors, including PA and SB. Furthermore, studies using PA accelerometer devices in large cohorts are needed to well characterize 24-hour daily activity, including sleep. Future sleep research using actigraphy should consider the importance of device integration to contribute to both sleep research and community-based PA research. Given the independent relationships between sleep, PA, SB, and health outcomes, it is relevant to understand how these behaviors interrelate and accumulate throughout the day to impact health. Furthermore, it is important to understand that 24-hour assessments of activity behaviors will help expand our understanding of the relationship between sleep and health and may help determine the best treatment options available including behavior modification interventions and therapies with multiple behavior targets.

Conflicts of interest

The authors declare no conflicts of interest. The results of the present study do not constitute endorsement by ACSM. The results of this study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

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