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Free-living cross-comparison of two wearable monitors for sleep and physical activity in healthy young adults

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HIGHLIGHTS

- Sleep and physical activity/sedentary behaviors impact health.
- Validation of monitors for assessing the full 24 h spectrum of behaviors is lacking.
- We cross-compared two standard monitors to assess sleep and physical activity.
- The GT3X+ showed good agreement with AW-64 for assessing sleep.
- There was a lack of agreement between AW-64 and GT3X+ for physical activity.

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ABSTRACT

There is a growing need for free-living monitoring of the full 24 h spectrum of behaviors with a single or integrated set of sensors. The validity of field standard wearable monitors in sleep and physical activity have yet to be assessed for the complementary behavior in the context of 24 h continuous monitoring. We conducted a free-living comparison study of the Actigraph GT3X+ (GT3X+) to assess sleep parameters as compared with the Actiwatch-64 (AW-64) and concurrently, the AW-64 to assess sedentary and physical activity behaviors as compared with the GT3X+. Thirty young adults (15 female, 19.2 ± 0.86 years) wore both monitors for 3 consecutive days and 2 consecutive nights. Agreement of sleep, sedentary, and physical activity metrics were evaluated using analyses of variance, intraclass correlation coefficients, Bland-Altman plots with associated confidence limits, mean absolute percentage of errors and equivalence tests. For sleep, the GT3X+ showed high agreement for total sleep time and sleep efficiency, but underestimated wakefulness after sleep onset and sleep onset latency relative to the AW-64. For sedentary behavior and physical activity, the AW-64 showed a moderate agreement for activity energy expenditure, but not for sedentary, light or moderate-vigorous physical activities relative to the GT3X+. Overall our results showed good agreement of the GT3X+ with AW-64 for assessing sleep but a lack of agreement between AW-64 and GT3X+ for physical activity and sedentary behaviors. These results are likely due to the monitor placement (wrist vs hip), as well as the algorithm employed to score the data. Future validation work of existing and emerging technologies that may hold promise for 24 h continuous monitoring is needed.

1. Introduction

Recently, several cost-effective systems have been developed to objectively monitor sleep and physical activity in real-world environments. Accelerometry is a widely used ecological, non-invasive technology and cost-effective substitute for both polysomnography (PSG), the gold standard for sleep monitoring [1], and indirect calorimetry [2], the gold standard for physical activity. Accelerometry provides objective monitoring of sleep-wake rhythm [3] and physical activity behavior [4] in free-living settings based on the recording of motion. Body movements are recorded by an accelerometer, which can be worn on the wrist, ankle, or hip. For sleep assessment the device is typically worn on the non-dominant wrist, and this technique has shown acceptable agreement with PSG, ranging between 85% and 95% for the identification of sleep-wake epochs [5], and for a similar sleep-wake detection ability of systems with dry electrodes [6, 7], at least for healthy adults (but see [8–10] about limits of these devices with paediatric and sleep disorder populations). Similarly, new accelerometer

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monitors show acceptable agreement with indirect calorimetry, a reliable measure of energy expenditure for waking activities, when worn in the hip [11].

Accelerometry systems may be used to concurrently assess sleep and physical activity behaviors in free-living settings. Measuring the full 24 h cycle with a single monitor would be a potentially convenient and cost-effective way to collect information about health and well-being [12]. Indeed, both sleep and physical activity/sedentary behaviors impact health [13], with both sedentary behaviors [14, 15] and poor sleep quality [16, 17] being associated with negative health outcomes. In addition, the dynamic interaction between these behaviors in the 24 h day mediates health outcomes. For example, higher sleep quality increases energy and reduces fatigue levels [18]. Reciprocally, greater physical activity ameliorates sleep quality [12, 18]. Moreover, the optimal combination between time spent sleeping and time spent in active behaviors (both light and moderate to vigorous physical activities) is associated with lower cardiovascular risk [19]. Thus, continuous, free-living monitoring of the full 24 h spectrum is needed to better understand the unique and combined impacts of these health behaviors.

However, current standard wearable monitors in sleep and physical activity are not well-validated for complementary behaviors during the 24 h period. For example, only a small number of studies have assessed the validity of the GT3X+ accelerometer (Actigraph, Pensacola, Florida, USA), a commonly used monitor for measuring physical activity and sedentary behaviors [20–22], to detect sleep-wake patterns against a concurrent PSG recording [23–25]. These studies showed that GT3X+ showed a systematic underestimation of wakefulness (i.e., both sleep latency and wake after sleep onset (WASO)), as well as a device placement effect. When the device was worn on the wrist, the typical position for sleep trackers, accuracy, sensitivity and specificity values were comparable to previous reports of other similar devices [23, 25], but not when worn on the hip [24, 25]. Overall, the wrist–worn GT3X+ appeared to be valid for detecting sleep/wake patterns in a laboratory setting. However, to our knowledge the ability of this device to monitor sleep in a free-living environment has not yet been studied.

In contrast, the Actiwatch-64 (AW-64; Phillips Respironics, Bend, Oregon, USA) is a validated and widely-used wearable monitor for sleep in both healthy and clinical populations [23, 26, 27], as well as children [8, 28]. This wrist-worn monitor is commonly used in clinical settings [29–31] and is one of the most trusted wearable monitors for sleep assessment. However, validation studies investigating the ability of this monitor to accurately assess physical activity behaviors in adults are lacking.

There is an important knowledge gap in understanding the accuracy of these commonly used wearable monitors for measuring the full 24 h spectrum of behaviors. The current study aimed to establish the agreement of these monitors in estimating both sleep and physical activity parameters under free-living conditions. Specifically, the aims are two-fold: a) to determine the agreement of the Actigraph (GT3X+) in measuring sleep parameters as compared with the Actiwatch-64 (AW-64) and b) to determine the agreement of the AW-64 in measuring sedentary and physical activity behaviors as compared with the GT3X+.

2. Method and materials

2.1. General study design

Study participants had no personal history of neurological, psychological, or other chronic illness. Participants reporting irregular sleep-wake schedules (i.e., reporting a habitual time in bed (TIB) longer or shorter than 7–9 h per night) or excessive levels of average daytime sleepiness (i.e., scores > 10), as measured by the Epworth Sleepiness Scale [32], were excluded from the study. Additionally, any participant currently experiencing symptoms of a sleep disorder determined during an in-person or phone interview with an experimenter were excluded from the study. Each participant gave informed consent prior to participation in the study, which was approved by the University of California at Riverside Human Research Protections Program, and received financial compensation or course credit for participating in the study.

Participants came to the Sleep and Cognition Lab at UC Riverside to receive the two study monitors (AW-64 and GT3X+). The field-based standard criterion for sleep was the AW-64. The field-based standard criterion for physical activity and sedentary behaviors was the GT3X+. Both monitors were initialized from the same computer prior to the participant visit and the clocks were synchronized in order to compare their output. Each participant wore both monitors for 3 consecutive days and 2 consecutive nights. Participants were instructed to wear the GT3X+ on the hip during the day using an elastic waistband that could be worn underneath clothing, and to move the monitor to be worn on a wristband at night. While a full 24 h wrist-worn protocol was considered, the decision for hip placement during the day was made to accommodate our goal to provide the best field-based criterion measure of free-living physical activity and sedentary behavior. While wrist placement is emerging for physical activity assessment, currently the best measurement potential remains the hip location [4]. The AW-64 was worn continuously on the non-dominant wrist. Participants were instructed to wear the monitors at all times for the next three days and two nights, and to remove them only when there was a chance the monitor could be damaged, i.e., coming in contact with water or playing a high-impact sport.

2.2. Wearable monitors

The AW-64 (Phillips Respironics, Bend, Oregon, USA) consists of a piezoelectric accelerometer with a vertical acceleration sensitivity of 0.02 g, a sampling rate of 32 Hz and a storage capacity of 64 kb. The GT3X+ (Actigraph, LLC, Pensacola, FL, USA) contains a tri-axial accelerometer with a sensitivity of 0.05 g and the sampling rate ranges from 30 to 100 Hz. Both monitors allow the recording and storage of several weeks of sleep-wake activity data. Since the ActiLife 6.4.3 software (Actigraph, LLC Pensacola, Florida, USA) automatically scores sleep using 60-s epoch cycles, even if the GT3X+ is initialized to collect data in 30-s epochs or shorter, both devices were initialized to collect data in 1-min epochs.

2.3. Sleep data processing

AW-64 sleep-recordings were analyzed using Actiware 5.52.0003 (Phillips Respironics, Bend, Oregon, USA) software. Data were scored using a proprietary algorithm provided by the software with three different sensitivity threshold levels, which refer to the number of activity counts used to define wake: Low (20 activity counts/epoch), Medium (40 activity counts/epoch), and High (80 activity counts/epoch).

GT3X+ data were analyzed with ActiLife 6.4.3 using the Sadeh sleep scoring algorithm [33]. We scored our data with both the default setting (ACT) and the Low Frequency Extension (LFE) setting. The LFE option has been designed to lower the band-pass filter threshold for signal detection.

All analyses were confined to the period between lights off and lights on, which was defined by bed times and wake times reported by the participants [34, 35]. The following sleep parameters were examined for the two systems: total sleep time (TST), defined as the number of minutes scored as sleep between lights off and lights on; sleep onset latency (SL), the number of minutes between lights out and the first epoch scored as sleep; wake after sleep onset (WASO), the number of minutes scored as wake after sleep onset; and sleep efficiency (SE), the ratio between TST and total time spent in bed. For both monitors these parameters were directly extracted from the output of the respective software packages.