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Measures of sleep and cardiac functioning during sleep using a multi-sensory commercially-available wristband in adolescents

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HIGHLIGHTS

- Accuracy of FitbitChargeHR™ to assess sleep and heart rate during sleep is tested.
- Fitbit device is reliable in detecting standard polysomnographic (PSG) metrics.
- Fitbit device performed well in detecting heart rate during sleep.
- Similar to standard actigraphy, Fitbit device had lower ability in detecting wake.
- FitbitChargeHR™ may be a valid alternative to PSG in healthy populations.

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ABSTRACT

To validate measures of sleep and heart rate (HR) during sleep generated by a commercially-available activity tracker against those derived from polysomnography (PSG) in healthy adolescents. Sleep data were concurrently recorded using FitbitChargeHR™ and PSG, including electrocardiography (ECG), during an overnight laboratory sleep recording in 32 healthy adolescents (15 females; age, mean ± SD: 17.3 ± 2.5 years). Sleep and HR measures were compared between FitbitChargeHR™ and PSG using paired *t*-tests and Bland-Altman plots. Epoch-by-epoch analysis showed that FitbitChargeHR™ had high overall accuracy (91%), high sensitivity (97%) in detecting sleep, and poor specificity (42%) in detecting wake on a min-to-min basis. On average, FitbitChargeHR™ significantly but negligibly overestimated total sleep time by 8 min and sleep efficiency by 1.8%, and underestimated wake after sleep onset by 5.6 min ($p < 0.05$). Within FitbitChargeHR™ epochs of sleep, the average HR was 59.3 ± 7.5 bpm, which was significantly but negligibly lower than that calculated from ECG (60.2 ± 7.6 bpm, $p < 0.001$), with no change in mean discrepancies throughout the night. FitbitChargeHR™ showed good agreement with PSG and ECG in measuring sleep and HR during sleep, supporting its use in assessing sleep and cardiac function in healthy adolescents. Further validation is needed to assess its reliability over prolonged periods of time in ecological settings and in clinical populations.

1. Introduction

Adolescence is characterized by many psychophysiological developmental changes, including changes in sleep [1]. One of the most noticeable changes in sleep behavior across adolescence is an increased preference for evening activities, mostly driven by circadian factors, which leads to adolescents going to sleep later. In addition to these biological factors, social forces (e.g. early school start times) contribute to insufficient sleep and erratic sleep-wake patterns in adolescents, with high variability in sleep duration between weekdays and weekends [1]. Insufficient sleep in this population has been linked to several adverse consequences [2] including high risk for cardiovascular disease [3,4]. This is not surprising as, the autonomic nervous system (ANS) is still developing in adolescence [5], and it is well known that sleep plays a major role in the recovery of ANS function by providing an extended period of reduced cardiovascular effort [6].

Polysomnography (PSG) is the gold standard in sleep evaluation. PSG consists of recording and integrating measures of cortical

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electroencephalographic activity, muscle tone, and eye movements to characterize the structure of sleep. However, because it is expensive, time consuming, and requires well-trained technicians, PSG is impractical for multiples recordings in large numbers of subjects. To avoid these limitations, researchers have used actigraphy to infer sleep/wake states, which is particularly useful in clinical evaluations, for home recordings (which are more ecologically valid), and in populations where extended recordings are important to capture a full picture of sleep variability over time (such as across adolescence) [7,8]. Actigraphy is a non-invasive technique that uses a small accelerometer, usually placed on the non-dominant wrist, to measure an individual's movement. From these movement data, filters and algorithms have been developed to infer sleep and wake states [8]. The main advantages of actigraphy over PSG are its low cost, low intrusion, and ease of use [7]. Further, the long-lasting batteries and high-capacity storage of these devices allow for weeks of recording with little intervention from technicians after first activation. Previous research has found that, compared with PSG, actigraphy has high sensitivity (ability to detect sleep) but poor specificity (ability to detect wakefulness) [9–11]. These measures, however, vary as a function of the amount of night-time wakefulness [12] and are highly dependent on the algorithm used and the population studied [8].

Recent technological advances and, in particular, the rising popularity of wearable devices (expected to reach a value of $8.5 billion by 2020 in the United States, according to the U.S. Enterprise Wearables Market) [13] have brought to market several novel, inexpensive, and potentially useful tools to assess daily physical activity and sleep [14–22]. Technology has quickly progressed from the first accelerometer-based devices to, within only a few years, multisensory products. These devices can measure several common physiological signals in addition to movement, such as heart rate (HR), temperature, and skin conductance. It is not surprising, therefore, that researchers have started looking at these devices as an economical way to collect data on a scale that would have proven too burdensome to collect using PSG. However, before recommending their widespread adoption as a research tool, it is necessary to evaluate the accuracy, reliability, and limitations of these tools across a variety of populations [14,15,21–23].

To date, only a few studies have evaluated the validity of these newer devices to detect sleep against PSG [22]. We have previously evaluated the validity of Jawbone UP™ wristband (Jawbone, San Francisco, CA) against PSG in healthy adults ($N = 28$) [24] and in adolescents ($N = 65$) [25]. Our results showed that, similar to standard actigraphy, the Jawbone UP™ overestimates sleep and underestimates wakefulness, and the errors become worse with increasing night-time wakefulness. Two other studies have been conducted to assess the validity of Fitbit devices (Fitbit Inc., San Francisco, CA, USA): Classic™ (the first model released by Fitbit) and Ultra™ in measuring sleep compared with PSG. One study used a population of 24 healthy adults [26] and the other used a pediatric population of preschool and school-age children and adolescents, some of whom had obstructive sleep apnea [27]. Both studies reported high sensitivity and poor specificity for the Fitbit Classic™ and Ultra™. Also, Meltzer and colleagues [27] found greater discrepancies between PSG and Fitbit Ultra™ in adolescents (with a significant underestimation of wake after sleep onset of ~54 min) than in preschool or school-age children, suggesting that adolescents may exhibit more motionless wakefulness compared to younger children.

The current study aims to evaluate the validity of sleep and HR measures during sleep collected via the FitbitChargeHR™, a promising multi-sensory wristband, against PSG in a sample of healthy adolescents.

2. Materials and methods

2.1. Participants

Thirty-two healthy adolescents (15 females; age, mean ± SD: 17.3 ± 2.5 y; Body Mass Index, BMI, mean ± SD: 22.2 ± 3.6 $kg \cdot m^{-2}$; 27 Caucasian) participated in the study. They were recruited from the San Francisco Bay Area as part of an ongoing multisite study of neurodevelopment in adolescents aged 12–21 years old at baseline (the National Consortium on Alcohol and NeuroDevelopment in Adolescence, NCANDA) [28].

All participants underwent clinical screening, including the Semi-Structured Assessment for the Genetics of Alcoholism [29], to ensure they were free from major physical (e.g. heart disease, traumatic brain injury) and psychological disorders (e.g. major depression, substance use disorders). A clinical PSG also confirmed none of the participants suffered from major sleep disorders (apnea-hypopnea index and periodic limb movement index were <5 events per hour of sleep in all participants). None of the participants reported taking medication affecting sleep or cardiovascular function.

The study, including the informed consent/assent procedure, was approved by the Institutional Review Board at SRI International. Adult participants provided written consent to participate and minors provided written assent along with written consent from a parent/legal guardian. All consent and assent forms are kept on file. Participants received payment for their participation. All data from the FitbitChargeHR™ and PSG were anonymized with the use of participant codes.

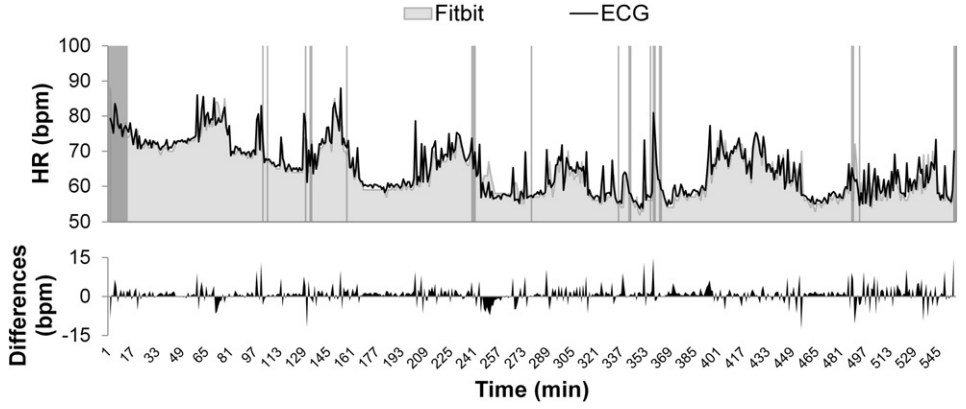

Fig. 1. Minute-by-minute heart rate (HR) across the night for a representative participant. Upper panel: HR (bpm) derived from the electrocardiogram (ECG, black) is superimposed on FitbitChargeHR™ HR (grey). Vertical bars show periods of wakefulness detected by FitbitChargeHR™ and are excluded from the analyses. Lower panel: Differences in HR (ECG minus FitbitChargeHR™) across the night.