https://doi.org/10.5664/jcsm.8980

JCSM | Journal of Clinical Sleep Medicine

SCIENTIFIC INVESTIGATIONS

Comparison of multichannel and single-channel wrist-based devices with polysomnography to measure sleep in children and adolescents

Sarah Burkart, MPH, PhD[1]; Michael W. Beets, MEd, MPH, PhD[1]; Bridget Armstrong, PhD[1]; Ethan T. Hunt, MPH[1]; Roddrick Dugger, MPH[1]; Lauren von Klinggraeff, MPH[1]; Alexis Jones, MS[1]; David E. Brown, MD[2]; R. Glenn Weaver, MEd, PhD[1]

[1]Department of Exercise Science, University of South Carolina, Columbia, South Carolina; [2]Department of Pediatrics, University of South Carolina School of Medicine, Columbia, South Carolina

Study Objectives: To compare sleep parameters produced by the Fitbit Charge 3 (Fitbit) and Actigraph GT9X accelerometer (Actigraph) to polysomnography in children and adolescents.

Methods: Participants (n = 56, ages 9.2 ± 3.3 years) wore a Fitbit and an Actigraph on their nondominant wrist concurrently with polysomnography during an overnight observation at a children's sleep laboratory. Total sleep time, sleep efficiency, wake after sleep onset, sleep onset, and sleep offset were extracted from the Fitabase and Actilife software packages, respectively, with the Sadeh algorithm. Bland-Altman plots were used to assess the agreement between wearable devices and polysomnography.

Results: Seventy-nine percent of participants were diagnosed with OSA. Compared with polysomnography, the Fitbit and the Actigraph underestimated total sleep time by 6.1 minutes (absolute mean bias [AMB] = 27.7 minutes) and 31.5 minutes (AMB = 38.2 minutes), respectively. The Fitbit overestimated sleep efficiency by 3.0% (AMB = 6.3%), and the Actigraph underestimated sleep efficiency by 12.9% (AMB = 13.2%). The Fitbit overestimated wake after sleep onset by 18.8 minutes (AMB = 23.9 minutes), and the Actigraph overestimated wake after sleep onset by 56.1 minutes (AMB = 54.7 minutes). In addition, the Fitbit and the Actigraph underestimated sleep onset by 1.2 minutes (AMB = 13.9 minutes) and 10.2 minutes (AMB = 18.1 minutes), respectively. Finally, the Fitbit and the Actigraph overestimated sleep offset by 6.0 minutes (AMB = 12.0 minutes) and 10.5 minutes (AMB = 12.6 minutes). Linear regression indicated significant trends, with the Fitbit underestimating wake after sleep onset and sleep efficiency at higher values.

Conclusions: The Fitbit provided comparable and in some instances better sleep estimates with polysomnography compared to the Actigraph. Findings support the use of multichannel devices to measure sleep in children and adolescents. Additional studies are needed in healthy children over several nights and in free-living settings.

Keywords: child, adolescent, polysomnography, accelerometry, sleep, wearable devices

Citation: Burkart S, Beets MW, Armstrong B, et al. Comparison of multichannel and single-channel wrist-based devices with polysomnography to measure sleep in children and adolescents. *J Clin Sleep Med.* 2021;17(4):645–652.

BRIEF SUMMARY

Current Knowledge/Study Rationale: Single-channel devices, such as accelerometers, estimate sleep parameters using movement data and are limited by their ability to detect wake periods during overnight sleep. Wearable devices that incorporate multichannel input (ie, heart rate and movement) may enhance sleep detection compared with single-channel devices.

Study Impact: Sleep parameter estimation in children and adolescents was comparable between the multichannel Fitbit Charge 3 and the single-channel Actigraph GT9X devices compared with polysomnography, with the Fitbit providing better estimates in some instances. Multichannel devices hold promise for sleep measurement in large samples of children and adolescents, but further validation studies are needed in healthy samples of children over several nights and in free-living settings (eg, in the home).

INTRODUCTION

Over the past 20 years, accelerometry has been a widely accepted measurement tool to assess sleep in settings where the gold standard, polysomnography (PSG), is not feasible (ie, free-living environments [such as in the home], longitudinal studies, large samples of patients).[1] Wrist-based accelerometry is advantageous compared with PSG because it is noninvasive, requires little to no effort on the part of the participant, and can be worn for extended periods of time. Accelerometers are single-channel devices that use data from a single sensor to measure movement during the night and apply algorithms to estimate sleep and wake periods.[2] In children and adolescents, wrist-based accelerometry is a valid and reliable way to measure sleep, yet the ability to detect wakefulness, based solely on movement, is poor.[3,4] This inability to accurately detect wakefulness during a sleep period, especially among those who experience greater night awakenings and movement (eg, OSA, periodic limb movement disorder), is commonly noted as a limitation in research studies, yet few advances have been made to improve this limitation.[1] This is problematic because inaccurate reporting of wake after sleep onset (WASO) alters other sleep parameter estimates such as total sleep time (TST) and sleep efficiency (SE).[5]

Differences between accelerometry and PSG sleep parameters are attributed to the single channel of input (ie, movement) from the accelerometer as compared with PSG, which simultaneously

collects multiple channels of data including brain activity, heart rate, eye movement, muscle tone, and movement.[1] Multichannel devices, such as those marketed by Fitbit, Garmin, and Polar, provide the same advantages of single-channel wrist-based devices (eg, inexpensive, low participant burden, record over several nights) but improve upon single-channel limitations by measuring heart rate via photoplethysmography in addition to accelerometer-measured movement. Devices that utilize two channels of data (ie, movement and heart rate) may provide better sleep estimates than single-channel (ie, movement) wrist-based devices when compared with PSG.[6]

To date, three studies have examined the validity of multichannel devices against PSG.[7–9] The multichannel devices examined included the Fitbit Charge HR,[8] the Fitbit Alta HR,[7] and the Polar A370.[9] Only 1 study validated estimates against in-laboratory PSG and found that the Fitbit Charge HR overestimated TST by 8.0 minutes, overestimated SE by 1.8%, and underestimated WASO by 5.6 minutes.[8] Further, these studies sampled predominantly adolescents, so validation studies including younger children are needed. Devices with multichannel input, such as some commercially available devices, have the potential to improve upon single-channel-only, accelerometry-based sleep estimates and hold promise for researchers interested in collecting objective sleep data in children and adolescents. Therefore, the purpose of this study was to compare sleep parameters produced by a multichannel device (ie, the Fitbit Charge 3 [Fitbit]; Firmware version 28.20001.63.5, Fitbit Inc., San Francisco, CA) and a single-channel device (ie, the Actigraph GT9X [Actigraph]; Firmware 1.7.2, Actigraph LLC, Pensacola, FL) with those produced by PSG in children and adolescents.

METHODS

Participants

Participants were recruited from a sleep clinic located at a local children's hospital that serves children from a greater metropolitan area in the southeastern United States. Children were referred for an overnight sleep study to this clinic by their pediatrician for conditions such as snoring, enlarged tonsils, or restless sleep. From November 2019 to February 2020, children (aged 3–17 years) and their families were mailed study information with their regularly scheduled appointment information. If they were interested in participating, then parents and children completed the consent packet and brought it to their appointment or completed it in the sleep clinic before the child's sleep study began. Parents completed an informed consent document and children completed an assent document (verbally if aged < 13 years). Children were excluded from participation if they were < 3 years or > 17 years or if a parent/guardian did not provide consent. Participating families received a $20 gift card after the completion of the study. All study procedures were approved by the lead author's institutional review board.

Polysomnography

The Cadwell Easy III equipment (Cadwell, Kennewick, WA) was used by trained sleep technicians to perform overnight PSG in the sleep center at a local children's hospital. Channels monitored included 4 electroencephalograms, 2 electrooculograms, 2-leg electromyography, electrocardiogram, snoring microphone, oxygen saturation, oro-nasal flow thermistor, nasal pressure transducer, abdominal respiratory movement, chest respiratory movement, chin electromyography, plethysmography, and end-tidal CO_2. Results were scored using the American Academy of Sleep Medicine pediatric scoring rules[10,11] and were interpreted by a pediatric sleep specialist.

Multichannel device

Children wore a Fitbit Charge 3 on their nondominant wrist simultaneously with a research-grade accelerometer while overnight PSG was conducted. Devices were placed by a trained sleep technologist and removed the following morning. The Fitbit combines movement data measured by triaxial accelerometry with heart rate variability measured by photoplethysmography to estimate sleep parameters using a proprietary algorithm. Each Fitbit was synced via Bluetooth to the Fitbit Connect app. Sleep parameter estimates were calculated by the Fitbit proprietary algorithm. Estimates were then extracted from Fitabase (Small Steps Labs LLC, San Diego, CA), a cloud-based data management software, and included measurements of TST, SE, WASO, sleep onset, and sleep offset. Fitabase was used because it allows researchers to batch-export Fitbit-generated sleep parameters. Initially, we also planned to validate the Garmin Vivosmart 4 (Garmin Inc., Olathe, Kansas) against PSG in this study, but this device was removed from the protocol because of device difficulties with inconsistent data collection. Garmin recommends wearing the device for at least 2 hours before bedtime to detect and record sleep, but this timeline was not possible in the current study.

Single-channel device

Children wore an Actigraph GT9× Link triaxial accelerometer on their nondominant wrist directly above the Fitbit. The Actigraph is a research-grade device frequently used with children participating in behavioral research.[3] Data were collected at a sampling rate of 30 Hz and downloaded in 1-second epochs. Sleep data were converted to 60-second epochs and processed in Actilife Software (version 6.13.4, Actigraph LLC, Pensacola, Florida) using the Sadeh algorithm.[3] Sleep reports were generated in Actilife, which produced estimates for each of the sleep parameters of interest.

Data analysis

Outcomes of interest included TST (minutes), WASO (minutes), sleep efficiency (percentage), sleep onset, and sleep offset because these were available from all 3 pieces of equipment. Descriptive statistics were calculated for participants' demographic information and all sleep parameters. Bland-Altman plots were constructed to show the level of agreement between the Fitbit, the Actigraph, and PSG for each sleep parameter.[12] Positive bias values indicated underestimation by the device, and negative bias values indicated overestimation by the device compared with PSG. Linear regression with the difference between devices (ie, PSG − Fitbit or PSG − Actigraph) as the independent variable and the PSG estimate as the dependent

variable was used to determine whether statistically significant trends in the bias were present for each parameter. All statistical analyses were conducted in Stata (version 16, StataCorp LLC, San Antonio, TX).

RESULTS

Of the 94 eligible children during the study period, 71 (76%) enrolled in the study. Children were excluded from analyses if they had incomplete data because of stopping PSG early (n = 1), Actigraph malfunction (n = 3), Fitbit malfunction (n = 6), or if they removed the device during the night (n = 1). The Fitbit may have failed to collect data if the device was not worn tight enough to detect heart rate throughout the night. In addition, 3 children were excluded from analyses because the parents did not release their child's PSG sleep report with parameters and diagnoses even though they initially consented to participate in the study. One child was also excluded because of complex coexisting medical conditions. Fifty-six children and adolescents (ages 9.2 ± 3.3 years, 55% female, 57% Black) had complete data and were included in the analyses. Most of the patients were diagnosed with OSA (after the PSG), and just under half fell within the obese weight category based on age- and sex-specific body mass index percentile categories (**Table 1**). Relative biases for each sleep parameter by age group (ie, ages 2–5, 6–11, and 12–17 years) are presented in **Table S1** in the supplemental material. Because of small sample sizes within age groups, specific age-related analyses were not conducted, and descriptive data should be interpreted with caution.

Table 1—Demographic characteristics of the sample (n = 56).

	n	%
Sex		
Male	25	44.6
Female	31	55.4
Race/ethnicity		
White	21	37.5
Black	32	57.1
Hispanic	3	5.4
BMI category		
Underweight	3	5.4
Normal or healthy weight	23	41.8
Overweight	4	7.3
Obese	25	45.5
Diagnosis		
Mild OSA	27	48.2
Moderate/severe OSA	17	30.4
Elevated periodic limb movement	4	7.1
None	8	14.3
	Mean	**SD**
Age (range, 3–17 y)	9.2	3.3
zBMI	1.0	1.4
PSG		
TST	370.9	53.0
Efficiency	88.0	10.7
Latency	20.1	26.5
WASO	30.1	34.8
Actigraph GT9×		
TST	341.1	46.3
Efficiency	75.8	9.4
Latency	25.6	31.4
WASO	84.4	37.9
Fitbit Charge 3		
TST	364.9	55.9
Efficiency	92.0	4.8
WASO	32.8	23.1

BMI = body mass index, PSG = polysomnography, SD = standard deviation, TST = total sleep time, WASO = wake after sleep onset, zBMI = body mass index z-score.

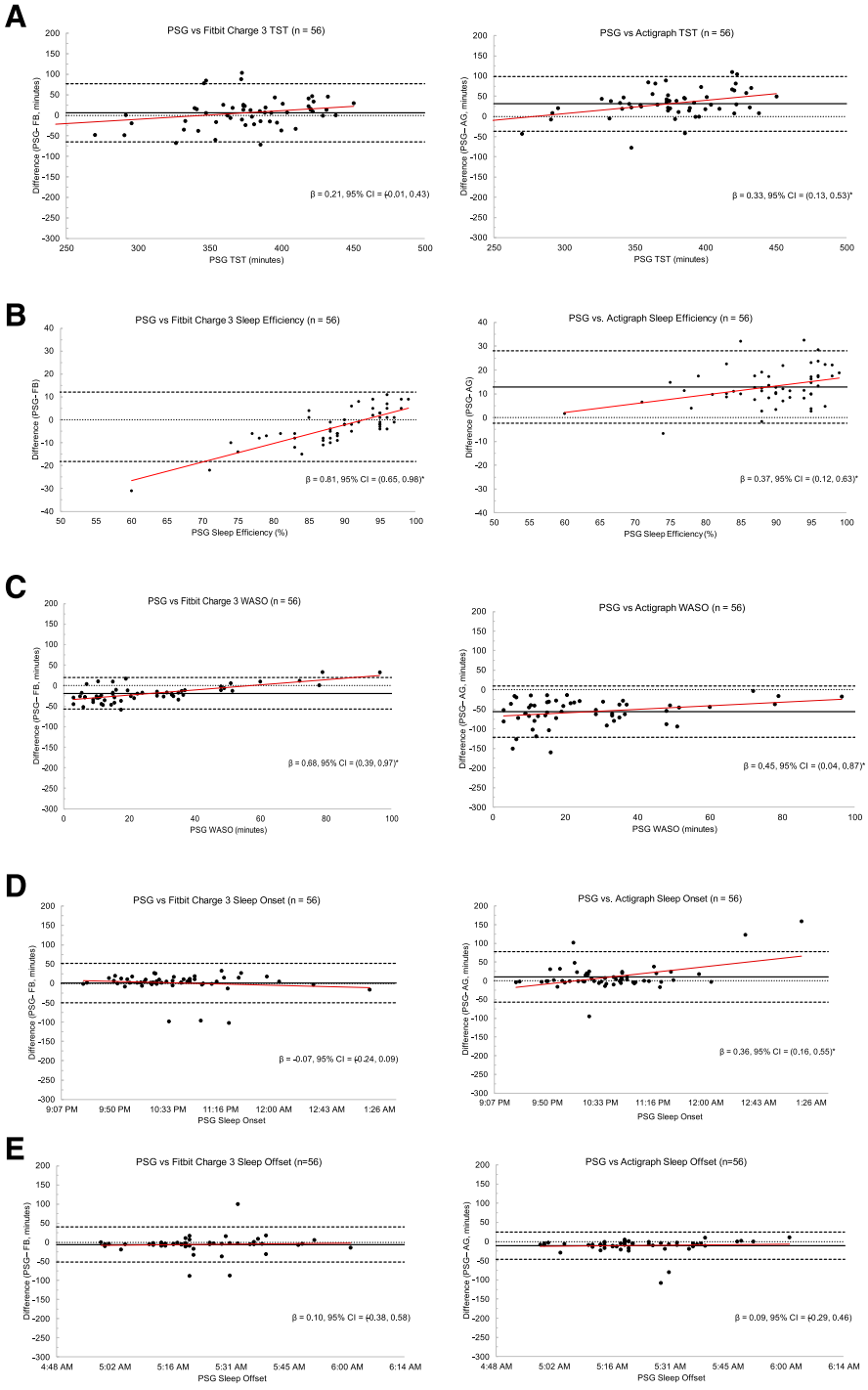
TST

According to PSG, children slept for approximately 6.2 hours on average on the night of data collection (**Table 1**). As shown in **Figure 1A,** the Fitbit underestimated TST by 6.1 ± 36.2 minutes compared with PSG, and the Actigraph underestimated TST by 31.5 ± 34.6 minutes. The limits of agreement for both devices showed a comparable range. The absolute mean bias (AMB) was 27.7 ± 23.8 minutes and 38.2 ± 26.9 minutes for the Fitbit and the Actigraph, respectively. There was a statistically significant positive trend in the Bland-Altman data between the Actigraph and PSG with a slope and standard error of 0.33 ± 0.10 (95% confidence interval [CI], 0.13–0.53; $P = .002$), suggesting that the Actigraph underestimated TST as TST increased. The direction and magnitude of differences between the devices and PSG were plotted with each bar representing an individual participant's overnight sleep (**Figure 2A**). The zero value in the figure indicates the PSG estimate. The green bar indicates an overlap in parameter estimation between the Fitbit and the Actigraph. When the bar emerges as blue or yellow, either the Fitbit (blue) or the Actigraph (yellow) had a greater difference in magnitude than the other. There were 8 instances (14%) where the Fitbit difference was greater than the Actigraph difference in the same direction, 25 instances (45%) where the Actigraph difference was greater than the Fitbit difference in the same direction, and 23 instances (41%) where the differences were in opposite directions.

SE

Average SE was 88% as reported by PSG. The Fitbit overestimated SE by 3.0% ± 7.7%, and the Actigraph underestimated SE by 12.9% ± 7.7% (**Figure 1B**). The limits of agreement for both devices showed a similar range. The AMB was slightly smaller for the Fitbit (6.3% ± 5.4%) than for the Actigraph (13.2% ± 6.7%). There was a statistically significant positive trend in the Bland-Altman data between the Fitbit and PSG with a slope of 0.81 ± 0.08 (95% CI, 0.65–0.98; $P < .001$). There was a similar trend in data between the Actigraph and PSG

Figure 1—Bland-Altman plots.



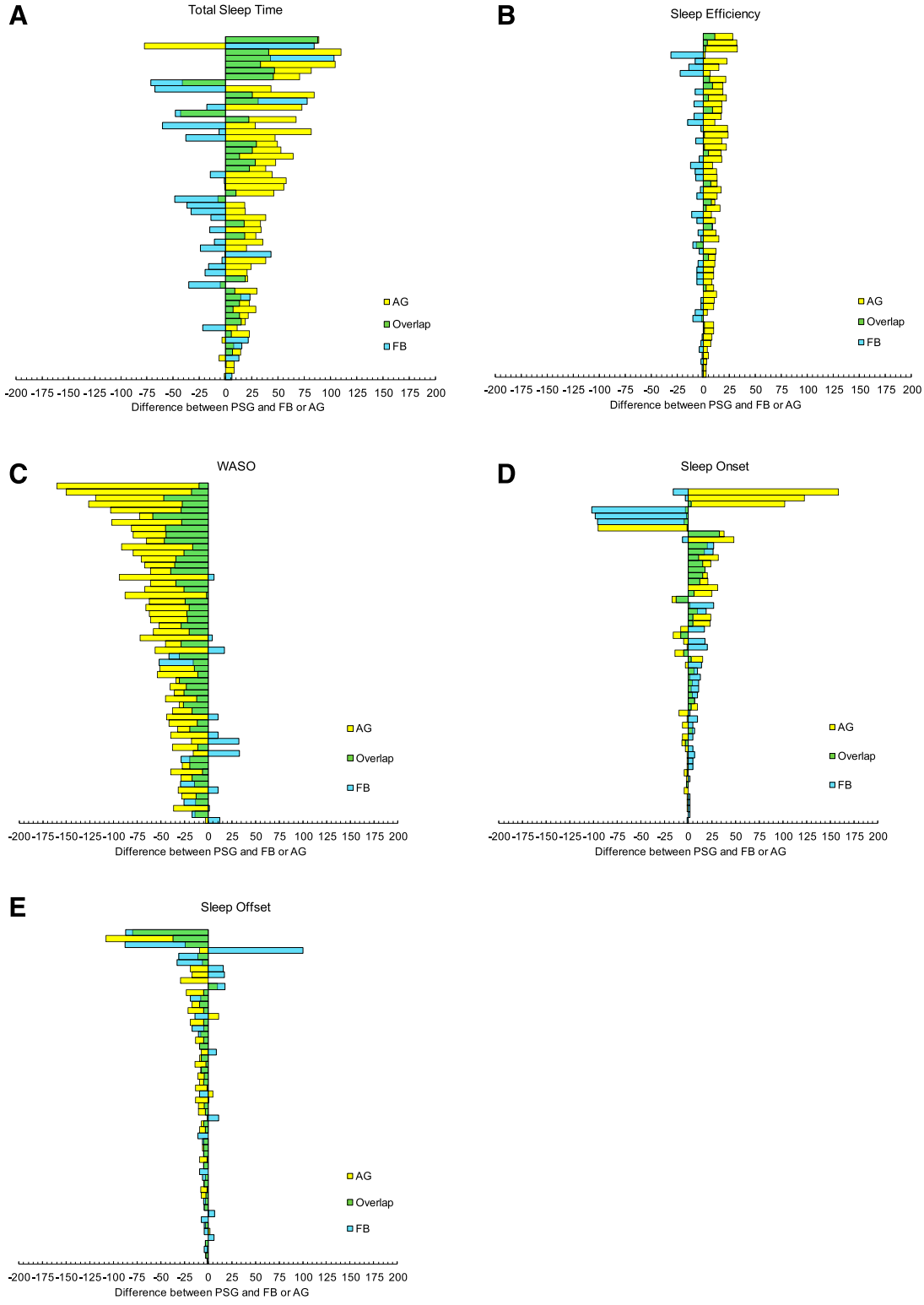
Bland-Altman plot of agreement for TST (**A**), SE (**B**), WASO (**C**), sleep onset (**D**), and sleep offset (**E**) when the Fitbit (left) and the Actigraph (right) were worn simultaneously and compared to PSG. The red line indicates the regression line where the difference between PSG and the device is the dependent variable and the PSG measure is the independent variable. *P <.05. AG = Actigraph, CI = confidence interval, FB = Fitbit Charge 3, PSG = polysomnography, SE = sleep efficiency, TST = total sleep time, WASO = wake after sleep onset.

with a slope of 0.37 ± 0.13 (95% CI, 0.12–0.63; P = .005), suggesting that both devices underestimated SE at higher values of SE. There were 3 instances (5%) where the Fitbit difference was greater than the Actigraph difference in the same direction, 18 instances (32%) where the Actigraph difference was greater than the Fitbit difference in the same direction, and 35 instances (63%) where the differences between devices were in opposite directions (**Figure 2B**).

WASO

During the overnight PSG, children experienced an average of 30 minutes of WASO. The Fitbit overestimated WASO by

Figure 2—Difference between Fitbit Charge 3 and Actigraph versus PSG.



Direction and magnitude of differences of the Fitbit Charge 3 and the Actigraph from the PSG estimates (defined as zero) for TST (**A**), SE (**B**), WASO (**C**), sleep onset (**D**), and sleep offset (**E**). AG = Actigraph, FB = Fitbit Charge 3, PSG = polysomnography, SE = sleep efficiency, TST = total sleep time, WASO = wake after sleep onset.

18.8 ± 19.5 minutes and the Actigraph overestimated WASO by 56.1 ± 33.6 minutes (**Figure 1C**). The Fitbit showed a narrower range in the limits of agreement. The Fitbit's AMB (23.9 ± 13.1 minutes) was nearly half that of the Actigraph (54.7 ± 33.2 minutes). There was a statistically significant positive trend for both the Fitbit, with a slope of 0.68 ± 0.14 (95% CI, 0.39–0.97;

$P < .001$), and the Actigraph, with a slope of 0.45 ± 0.21 (95% CI, 0.04–0.87; $P = .034$). This finding suggests that both devices tended to underestimate WASO at higher values of WASO. There were 6 instances (11%) where the Fitbit difference was greater than the Actigraph difference in the same direction, 40 instances (71%) where the Actigraph difference was greater than the Fitbit difference in the same direction, and 10 instances (18%) where the differences were in opposite directions (**Figure 2C**).

Sleep onset

In this sample of children and adolescents, the average sleep onset time was 10:41 PM based on PSG. The Fitbit underestimated sleep onset by 1.2 ± 25.8 minutes and the Actigraph underestimated sleep onset by 10.2 ± 34.5 minutes (**Figure 1D**). Similar to WASO, the limits of agreement for the Fitbit showed a narrower range. The Fitbit's AMB (13.9 ± 21.7 minutes) was slightly less than that of the Actigraph (18.1 ± 31.1 minutes). There was a statistically significant positive trend for the Actigraph, with a slope of 0.36 ± 0.10 (95% CI, 0.16–0.55), which indicates that this device underestimated sleep onset at later onset times. There were 15 instances (27%) where the Fitbit difference was greater than the Actigraph difference in the same direction, 19 instances (34%) where the Actigraph difference was greater than the Fitbit difference in the same direction, 19 instances (34%) where the differences were in opposite directions, and 3 instances (5%) where the differences were equal in the same direction (**Figure 2D**).

Sleep offset

The average sleep offset time as reported by PSG was 5:22 AM. The Fitbit and the Actigraph similarly overestimated sleep offset by 6.0 ± 23.3 minutes and 10.5 ± 18.1 minutes, respectively (**Figure 1E**). The Actigraph had a narrower range in the limits of agreement. The AMB was nearly identical for the Fitbit (12.0 ± 20.5 minutes) and the Actigraph (12.6 ± 19.8 minutes). There were no statistically significant trends in the data for either device. There were 18 instances (32%) where the Fitbit difference was greater than the Actigraph difference in the same direction, 23 instances (41%) where the Actigraph difference was greater than the Fitbit difference in the same direction, 9 instances (16%) where the differences were in opposite directions, and 6 instances (11%) where the differences were equal in the same direction (**Figure 2E**).

DISCUSSION

The goal of this study was to evaluate the validity of a multichannel wrist-based device (ie, the Fitbit Charge 3) that combines accelerometry and photoplethysmography to detect sleep and wake periods. We compared Fitbit and Actigraph measures of TST, SE, WASO, sleep onset, and sleep offset against PSG, the gold-standard measure, in a sample of children and adolescents with suspected sleep disorders. Findings indicated that the Fitbit performed as well as and in most instances better than the Actigraph when compared with PSG.

Previous validations of multichannel devices have focused exclusively on healthy participants.[7–9] Four previous studies have assessed the agreement between commercially available devices and PSG in children with suspected and diagnosed OSA, but these studies utilized single-channel devices (ie, movement only).[13–16] Three of these 4 studies reported an overestimation of TST by 10–40 minutes,[14–16] and all reported an underestimation of WASO by 9–32 minutes.[13–16] The present study found results in the opposite direction, with the Fitbit underestimating TST by 6 minutes and overestimating WASO by 19 minutes. The combination of movement and heart rate in the newer Fitbit sleep detection algorithm (ie, found in the Fitbit Charge 3) has been shown to more accurately detect wakefulness during sleep periods in adults[17] and thus may show a similar pattern in children and adolescents. The inclusion of heart rate measurement seems to be a key improvement over single-channel devices, which generally overestimate TST and inaccurately detect WASO especially with greater time spent awake after sleep onset.[5,17]

To date, only three studies have been conducted to validate and assess the agreement between multichannel devices (ie, movement and heart rate) and PSG.[7–9] None of these studies are directly comparable to the current study because each used different single- and multichannel devices, sampled different age groups, and used PSG in various settings. Because different multichannel devices were used in each of these studies, it is possible that the devices' proprietary algorithms differed, which may explain the difference in findings. However, all three studies found that the tested multichannel device provided similar if not more accurate measures of sleep than single-channel accelerometry when compared with PSG. Of the three studies, our findings were most similar in terms of direction to those of Pesonen and Kuula,[9] who examined the Polar A370 device (Polar Electro Inc., Lake Success, NY) against PSG. The authors reported an underestimation of 29 and 21 minutes for TST, an overestimation of 24 and 12.5 minutes for WASO, and an underestimation of 4.5% and 3% for SE in 17 school-aged children (ages 9–11 years) and 17 adolescents (ages 17–19 years), respectively.[9] In addition, theirs has been the only study to report agreement for sleep onset and offset and found that the Polar A370 overestimated sleep onset by 5 and 13 minutes for the school-aged and adolescent age groups, respectively.[9] Finally, sleep offset in their study was equivalent in the school-aged group and underestimated by 1 minute in the adolescent age group.[9] This finding is similar to our reported underestimation of sleep onset by 1 minute and overestimation of sleep offset by 6 minutes for the Fitbit. Differences across both studies in sleep onset and offset are likely clinically negligible. Both studies drew similar conclusions that the tested multichannel devices perform as well as single-channel devices and that the discrepancies from PSG seem to be somewhat less in multichannel devices than in research-grade single-channel devices.

Lee, Chee, Ong, et al[7] examined the agreement between the Fitbit Alta HR and a quasi-laboratory-based PSG (ie, limited PSG setup) in a boarding school over several nights with different sleep durations in 58 adolescents (ages 15–19 years). The Fitbit Alta HR underestimated TST by 24–47 minutes and overestimated WASO by 21–41 minutes.[7] In de Zambotti, Baker, Willoughby, et al,[8] the Fitbit Charge HR was compared with standard laboratory-based PSG in 32 adolescents and

showed an overestimation of TST by 8 minutes, an overestimation of SE by 2%, and an underestimation of WASO by 6 minutes. The authors found that differences in WASO between the Fitbit and PSG were greater at higher values of WASO,[8] which was also shown in the present study. This result suggests that detecting wakefulness becomes more difficult with disrupted sleep. Although both studies utilized Fitbit brand devices that included heart rate, it is important to note that the Fitbit company updated its sleep tracking technology in 2017, and this proprietary advanced sleep detection was not available in the Fitbit Charge HR. The previous algorithm used by the Fitbit Charge HR yielded time awake, restless sleep, and sleep. Once updated in new models (including the Fitbit Alta HR and Charge 3), time awake and restless sleep were combined into total minutes awake. This change likely resulted in an underestimation of time spent awake in previously researched sleep data.

Both Lee, Chee, Ong, et al[7] and de Zambotti, Baker, Willoughby, et al[8] included only adolescents in their studies, which may contribute to the different findings compared with those in the present study. Previously, de Zambotti, Baker, and Colrain[18] suggested that agreement between commercially available devices and PSG exists along a continuum from early childhood through adolescence. This stems from evidence by Meltzer, Walsh, Traylor, et al,[19] which showed that a single-channel wrist-based device underestimated TST in early and middle childhood yet overestimated TST in adolescence. Further, those authors observed an overestimation of WASO in early and middle childhood compared with an underestimation of WASO in adolescence.[19] Changes in sleep duration (ie, decreased TST), timing (ie, later bedtime), and sleep architecture (ie, decreased deep sleep) are common during adolescence[20] and may explain age differences in agreement between devices. When we examined the biases among different age groups in our sample of children and adolescents, we observed noticeable differences in TST but not in WASO as previously reported. The Fitbit underestimated TST by 35.9 minutes in children aged 2–5 years but had similar biases of less than 1 minute for groups aged 6–11 and 12–17 years (**Table S1**). The Fitbit overestimated WASO by 16–23 minutes across all age groups. Therefore, our younger participants (mean age, 9.2 ± 3.3 years), in comparison to previous work by Lee, Chee, Ong, et al[7] (mean age, 16.6 ± 0.9 years) and de Zambotti, Baker, Willoughby, et al[8] (mean age, 17.3 ± 2.5 years), seemed to be driving the observed underestimation of TST.

Findings should be interpreted within the context of the study's limitations. We do not have access to Fitbit's raw sleep data, nor do we know the proprietary algorithm used to estimate sleep parameters. This missing information limits our ability to understand how heart rate and accelerometry are incorporated into these calculations. The current sample of children and adolescents were referred to the sleep clinic by their physician for suspected sleep difficulties. Approximately 79% of the participants in the sample were diagnosed with some degree of OSA. Because there are clinical differences in sleep (eg, increased arousal, snoring, disruption) between children with and without OSA, these results may not be generalizable to the general population. Further work is needed to examine the validity of multichannel devices to detect sleep in children with and without sleep disorders. Despite the use of the gold-standard criterion measure (ie, PSG), this methodological choice also limits our ability to understand how multichannel devices may measure sleep over several days and how sleep behavior may differ in the natural home environment. Future studies should explore the validity and utility of these devices in free-living settings across multiple nights. Finally, because of time constraints of the sleep technologists, the sleep laboratory where we conducted this study was only able to provide summary reports from the PSG recordings. These reports did not contain minute-by-minute data and limited our ability to calculate sensitivity, specificity, and additional sleep metrics. We were thus unable to determine at what points during the overnight recording the devices differed in parameter estimation, which prevents intraindividual comparison.

The strengths of this study include the comparison of single- and multichannel devices against a gold-standard measurement technique. Further, participants wore the single- and multichannel device on the same wrist simultaneously, which allowed for the direct comparison between devices versus PSG. This is the first study to validate the Fitbit Charge 3 in a sample of children and adolescents. As new technology emerges, it is important to continue to validate these devices before use in research studies.

Overall, findings suggest that a multichannel device (Fitbit Charge 3) performs as well as and in some instances better than a single-channel device (Actigraph GT9X) for measuring sleep when compared with PSG in children and adolescents with diagnosed sleep disorders. This newer technology may improve upon the limitations of single-channel devices that solely rely on accelerometry to detect sleep and wakefulness. Further testing is needed in healthy and other clinical samples of youth in a free-living environment and over several nights.

ABBREVIATIONS

Actigraph, Actigraph GT9X Link accelerometer
AMB, absolute mean bias
CI, confidence interval
Fitbit, Fitbit Charge 3
PSG, polysomnography
SE, sleep efficiency
TST, total sleep time
WASO, wake after sleep onset

REFERENCES

1. Goldstone A, Baker FC, de Zambotti M. Actigraphy in the digital health revolution: still asleep? *Sleep*. 2018;41(9):zsy120.
2. Van de Water AT, Holmes A, Hurley DA. Objective measurements of sleep for non-laboratory settings as alternatives to polysomnography—a systematic review. *J Sleep Res*. 2011;20(1 Pt 2):183–200.
3. Sadeh A. The role and validity of actigraphy in sleep medicine: an update. *Sleep Med Rev*. 2011;15(4):259–267.
4. Meltzer LJ, Montgomery-Downs HE, Insana SP, Walsh CM. Use of actigraphy for assessment in pediatric sleep research. *Sleep Med Rev*. 2012;16(5):463–475.
5. Paquet J, Kawinska A, Carrier J. Wake detection capacity of actigraphy during sleep. *Sleep*. 2007;30(10):1362–1369.

6. Depner CM, Cheng PC, Devine JK, et al. Wearable technologies for developing sleep and circadian biomarkers: a summary of workshop discussions. *Sleep*. 2020;43(2):zsz254.
7. Lee XK, Chee NIYN, Ong JL, et al. Validation of a consumer sleep wearable device with actigraphy and polysomnography in adolescents across sleep opportunity manipulations. *J Clin Sleep Med.* 2019;15(9):1337–1346.
8. de Zambotti M, Baker FC, Willoughby AR, et al. Measures of sleep and cardiac functioning during sleep using a multi-sensory commercially-available wristband in adolescents. *Physiol Behav.* 2016;158:143–149.
9. Pesonen A-K, Kuula L. The validity of a new consumer-targeted wrist device in sleep measurement: an overnight comparison against polysomnography in children and adolescents. *J Clin Sleep Med.* 2018;14(4):585–591.
10. Berry RB, Brooks R, Gamaldo C, et al. AASM scoring manual updates for 2017 (version 2.4). *J Clin Sleep Med.* 2017;13(5):665–666.
11. Berry RB, Brooks R, Gamaldo CE, et al. *The AASM Manual for the Scoring of Sleep and Associated Events: Rules, Terminology and Technical Specifications.* Version 2.0. Darien, IL: American Academy of Sleep Medicine; 2012.
12. Krouwer JS. Why Bland-Altman plots should use X, not (Y+X)/2 when X is a reference method. *Stat Med.* 2008;27(5):778–780.
13. Osterbauer B, Koempel JA, Ward SLD, Fisher LM, Don DM. A comparison study of the Fitbit activity monitor and PSG for assessing sleep patterns and movement in children. *J Otolaryngol Adv.* 2016;1(3):24.
14. Toon E, Davey MJ, Hollis SL, Nixon GM, Horne RS, Biggs SN. Comparison of commercial wrist-based and smartphone accelerometers, actigraphy, and PSG in a clinical cohort of children and adolescents. *J Clin Sleep Med.* 2016;12(3):343–350.
15. Hakim M, Miller R, Hakim M, et al. Comparison of the Fitbit Charge and polysomnography for measuring sleep quality in children with sleep disordered breathing [published online ahead of print, 2018 Nov 7]. *Minerva Pediatr.* doi: 10.23736/S0026-4946.18.05333-1.
16. Meltzer LJ, Hiruma LS, Avis K, Montgomery-Downs H, Valentin J. Comparison of a commercial accelerometer with polysomnography and actigraphy in children and adolescents. *Sleep*. 2015;38(8):1323–1330.
17. Haghayegh S, Khoshnevis S, Smolensky MH, Diller KR, Castriotta RJ. Accuracy of wristband Fitbit models in assessing sleep: systematic review and meta-analysis. *J Med Internet Res.* 2019;21(11):e16273.
18. de Zambotti M, Baker FC, Colrain IM. Validation of sleep-tracking technology compared with polysomnography in adolescents. *Sleep*. 2015;38(9):1461–1468.
19. Meltzer LJ, Walsh CM, Traylor J, Westin AM. Direct comparison of two new actigraphs and polysomnography in children and adolescents. *Sleep*. 2012;35(1):159–166.
20. Colrain IM, Baker FC. Changes in sleep as a function of adolescent development. *Neuropsychol Rev.* 2011;21(1):5–21.

ACKNOWLEDGMENTS

The authors thank the sleep technologists at the Children's Sleep Lab for their help with this study.

SUBMISSION & CORRESPONDENCE INFORMATION

Submitted for publication June 23, 2020
Submitted in final revised form November 3, 2020
Accepted for publication November 3, 2020
Address correspondence to: Sarah Burkart, MPH, PhD, Department of Exercise Science, Arnold School of Public Health, 921 Assembly Street, Columbia, SC 29208; Tel: (803) 777-0275; Email: sburkart@mailbox.sc.edu

DISCLOSURE STATEMENT

All authors have seen and approved the manuscript. The authors report no conflicts of interest.