Original Paper

Feasibility of Using Consumer-Grade Wearables Among Adolescents Presenting for Specialty Concussion Care: Prospective Longitudinal Cohort Study

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Abstract

Background: Autonomic dysfunction is common after concussion and may be compounded by inactivity. Accordingly, physical activity progression is an important component of concussion rehabilitation. Fitbit devices can provide objective longitudinal data on physical activity, physiologic response to activity, and sleep. However, participants must have adequate adherence to device wear to provide accurate data. The threshold for adequate adherence may change based on the research question, making it important to understand how adherence changes across different thresholds. Furthermore, it is unclear how much staff support (ie, reminders) may be required to maintain an adequate level of adherence.

Objective: This study aimed to (1) evaluate adherence to Fitbit device wear during daytime and nighttime using 3 different thresholds (50%, 75%, and 90% wear time) over 13 weeks in adolescents presenting for specialty concussion care and (2) report the number of reminders required to achieve the observed level of adherence.

Methods: A total of 80 adolescents were recruited from a specialty concussion clinic. Participants were asked to wear a Fitbit Sense 2 device day and night for 1 year. We analyzed data collected during the first 13 weeks. For each threshold, a day or night was considered valid if the percentage of minutes with recorded heart rate data was greater than or equal to the defined threshold. We fit 2 robust linear mixed-effects models with number of valid days or valid nights as the outcome, a fixed effect for time (week), a fixed effect for threshold (50%, 75%, and 90%), a time-by-threshold interaction, and a random slope and intercept for each participant. We also calculated the percentage of participants who required a reminder from the study team to wear the device and/or synchronize it and the average number of manual reminders sent per participant across the study period.

Results: A total of 70 participants were included in the analyses. Over 13 weeks, adolescents had average daily adherence ranging from 3.0 (SD 0.7) to 4.4 (SD 0.8) days/wk and average nightly adherence ranging from 3.6 (SD 0.7) to 3.9 (SD 0.7) nights/wk. Across all thresholds, adherence was highest during the first week. The number of valid wear days (β=–0.2; P<.001) and nights (β=–0.2; P<.001) decreased each week, regardless of the adherence threshold used. A total of 50 of 70 (71%) participants required at least 1 manual reminder from the study team.

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Conclusions: We found that adolescents presenting for specialty concussion care had adequate adherence to Fitbit device wear over 13 weeks. Approximately three-quarters of the participants required at least 1 reminder from the study team. This suggests that collecting longitudinal data with a Fitbit device is feasible in adolescents presenting for specialty concussion care but that reminders are needed to promote adherence.

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KEYWORDS

concussion; Fitbit; wearable device; remote monitoring; adherence; youth; adolescents; physical activity

Introduction

At least 1 to 2 million youth in the United States are affected by concussion each year [1]. Physical, cognitive, emotional, and sleep symptoms often accompany a concussion [2] and can persist for multiple weeks after injury [3,4]. The majority of symptoms resolve within 3 months of injury [2]; however, approximately 30% of youth with concussion experience symptoms that persist beyond this typical recovery window [3-5].

It is hypothesized that persisting symptoms may be related to autonomic dysfunction [6,7]. Autonomic dysfunction is common after concussion [8,9] and may be compounded by inactivity early in the recovery process [7]. Clinical signs of autonomic dysfunction include fatigue, light-headedness, and abnormal exercise response [9]. To address this dysfunction, physical activity is an important component of the clinical management of concussion, particularly in the early stages of treatment [7,10,11]. Return-to-sport guidelines recommend a stepwise return to activity as tolerated, with the introduction of aerobic exercise within 24 to 48 hours of injury [11]. However, clinicians must rely on patient and caregiver reports to understand adherence to physical activity recommendations and tolerance of the recommended activity (ie, symptom exacerbation).

Consumer-grade wearable devices, such as Fitbit devices, present an opportunity for remote monitoring of physical activity, heart rate, and sleep data to provide objective longitudinal data that could support clinical decision-making [12,13]. However, to provide accurate physiologic and activity estimations, individuals must have adequate adherence to device wear [14]. The definition of adequate adherence will depend on the specific research or clinical question being evaluated. Using an adherence threshold that is too low can mischaracterize activity [14] and lead to inaccurate conclusions. However, not all questions will require the same threshold for adequate adherence. For example, estimating daily physical activity may require a higher adherence threshold (eg, 75% of the day with recorded heart rate data [15]) compared to estimating daily resting heart rate, for which a lower threshold may be appropriate [14]. Using a Fitbit device to estimate sleep parameters will likely require the highest adherence threshold, to ensure that participants wear the device throughout the desired sleep window [16]. A threshold commonly used in the physical activity literature is a wear time of greater than 10 hours [17]. However, this threshold may unnecessarily exclude participants if this wear time threshold is not necessary for the research question [18]. Therefore, it is important to understand how adherence may change across different thresholds.

Previous work has demonstrated the feasibility of collecting data using a Fitbit device among adolescent athletes with sport-related concussion for up to 6 months [19]. However, it is unclear whether adolescents presenting for specialty concussion care, including both athletes and nonathletes, can achieve adequate adherence to device wear. We may expect a difference in adherence when including nonathletes, as athletes have been found to be more likely than nonathletes to choose to use wearable devices [20]. Additionally, adolescents seeking specialty concussion care may be experiencing a greater symptom burden, which may affect adherence.

Importantly, obtaining data from a Fitbit device requires participants not only to wear the device but also to synchronize it with the Fitbit servers to ensure that researchers and clinicians can access the data. Youth have reported difficulty remembering to wear and synchronize their Fitbit device [21]. One strategy to improve adherence is to send participants reminders to wear and synchronize their Fitbit device. Previous work has described the use of reminders to encourage adolescent athletes to synchronize their Fitbit device [19]. However, the number of reminders typically required to achieve adequate adherence among adolescents after concussion has not been established. Previous work in adults with stroke and adults with chronic obstructive pulmonary disease found that, over 3 months, 65% of participants had to be contacted at least once to synchronize their Fitbit device [22]. This need for reminders suggests that an automatic reminder system or additional time and effort from research personnel may be necessary to achieve high levels of adherence. The frequency of contact needed to maximize adherence among adolescents is currently unknown.

Here, we report on adherence to remote physiologic monitoring with Fitbit smartwatches among adolescents with concussion presenting for specialty concussion care. We examined adherence using different wear time thresholds (50%, 75%, and 90%) during daytime and nighttime over 13 weeks. We also quantified the number of reminders sent to achieve the observed level of adherence.

Methods

Participants

Youth aged 13 to 18 years diagnosed with concussion were recruited from the Kennedy Krieger Multidisciplinary Concussion Clinic. To identify patients eligible for screening, charts of patients with scheduled concussion clinic visits were reviewed to identify those who were less than 6 months after

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concussion and within the age range of interest. Patients were not approached for screening if their parent or guardian was not fluent in English, they had pre-existing functional limitations (eg, severe developmental delay), their clinician preferred that the patient or family not be approached, the patient or family did not want to be approached, the patient had only telehealth visits scheduled, the patient was in foster care, or a member of the study team was not available to conduct the screening.

After the initial chart review, the identified patients were screened in-person at their scheduled concussion clinic visit. Patients were included if they were willing to wear an activity monitor, had Wi-Fi at home, and had access to a personal smartphone.

Ethical Considerations

The Johns Hopkins Medicine Institutional Review Board approved these procedures (IRB00247292). Oral assent was obtained from participants aged 13 to 17 years, and oral consent was obtained from their parent or guardian. Oral consent was obtained from participants aged 18 years. All participants kept the Fitbit Sense 2 device (Alphabet Inc) as compensation for participating in the study.

Experimental Procedures

Clinical Characteristics

Information on prior diagnoses (mental health, neurodevelopmental, and postural orthostatic tachycardia) was abstracted from medical charts and patient or caregiver interviews. Diagnoses were categorized as yes, no, or suspected but not diagnosed. A history of advanced sports participation [23] was also obtained from patients. To characterize symptom burden at the initial visit, we used the Rivermead Post-Concussion Symptoms Questionnaire [24]. The Rivermead Post-Concussion Symptoms Questionnaire lists 18 common postconcussive symptoms and asks participants to compare the symptoms they experienced in the past 24 hours with those experienced before the injury. The ratings for each symptom range from 0 (“not experienced”) to 4 (“severe problem”), for a total possible score of 72.

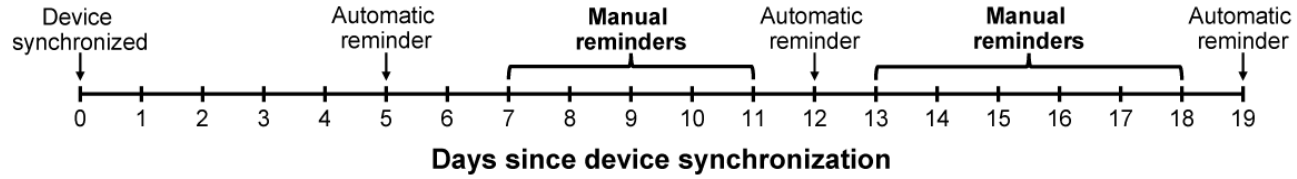
Remote Physiologic Monitoring

All participants received a Fitbit Sense 2 device to wear during the study period. Participants were asked to wear the Fitbit device day and night for 1 year. For this study, we analyzed the data collected during the first 13 weeks. Day 1 was defined as the day after device setup. The device was worn on the participant’s preferred wrist. A research team member assisted the participant in setting up their Fitbit account with a study-specific email account that did not include personal information. Heart rate and step count data were collected by the Fitbit device and transmitted to the Fitbit app on the participant’s smartphone. The participants were required to synchronize the Fitbit device with the Fitbit app to ensure data transfer. The Fitbit app then sent the data to the Fitbit API servers. A custom app developed by the Johns Hopkins Medicine Technology Innovation Center retrieved the data from the Fitbit API servers and transferred them to a secure Johns Hopkins server, where it was accessed by the study team to perform analyses.

Reminders

At enrollment, we collected each participant’s preferred contact information. This included the preferred contact person (ie, participant and/or parent or guardian), contact method (ie, text, phone call, or email), and contact time. We used a combination of automatic and manual reminders to attempt to maximize device wear and synchronization (Figure 1). Automatic text or email reminders were sent to the participant via a custom web application after 5, 12, and 19 days had passed without synchronization of the Fitbit device with the server [22]. After 7 or more days without synchronization, a study team member also sent a personalized manual reminder via each participant’s preferred contact method. The first manual reminder was sent 7 to 11 days after the last device synchronization, and the number of reminders sent during this time frame varied between participants. This variability was due to the availability of the study team. If we could not reach the participant or parent or guardian within 2 weeks of the last synchronization, despite multiple contact attempts per week, we attempted contact once a month for up to 3 months.

Figure 1. Reminder schedule. Automatic reminders were sent after 5, 12, and 19 days without device synchronization. Manual reminders were sent by a member of the study team after 7 days without synchronization.



Tracking Barriers to Adherence

When participants had problems wearing and/or synchronizing their Fitbit devices, we worked with them to identify barriers and suggested solutions. Barriers to adherence to device wear or Fitbit synchronization were logged.

Data and Statistical Analysis

Adherence to Device Wear

We first identified valid minutes of wear. A minute was considered valid if the Fitbit device recorded heart rate data. Next, we identified valid days and valid nights. We used 3 different thresholds to define adherence: 50%, 75%, and 90%. For each threshold, a day or night was considered valid if the percentage of minutes with recorded heart rate data was greater than or equal to the defined threshold (50%, 75%, or 90% of

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minutes) [22]. Daytime hours were defined as 7 AM to 9:59 PM, and nighttime hours were defined as 10 PM to 6:59 AM.

We calculated average adherence across 13 weeks for each adherence threshold. We defined adequate adherence as average weekly adherence of greater than or equal to 3 days [17]. We chose to define adequate adherence based on the recommendation from Chan et al [17], who suggested that 3 days per week of valid data are adequate to measure adherence and to estimate physical activity measures.

We were interested in how the number of valid days changed over 13 weeks, and whether changing the threshold for a valid day impacted adherence over time. To do this, we fit a robust linear mixed-effects model [25] with the number of valid days as the outcome, a fixed effect for time (week), a fixed effect for threshold (50%, 75%, and 90%), a time-by-threshold interaction, and a random slope and intercept for each participant. We used a robust model due to violations of the assumptions of linear regression (verified using the *performance* package [26]). If the fixed effect for threshold or the interaction term was significant, we used the *emmeans* package [27] to understand which thresholds and/or slopes were significantly different. To obtain 95% CIs for the robust linear mixed-effects model, we performed a nonparametric bootstrap with 1000 iterations [28].

We also performed the same analysis described above, examining the number of valid nights across 13 weeks.

We compared the average proportion of minutes the device was worn across the study period for both daytime and nighttime based on participants' advanced sports participation history, history of a prior mental health diagnoses, and history of prior neurodevelopmental diagnoses. For the purposes of this analysis, those who were in the suspected category for a prior mental health or neurodevelopmental diagnosis were moved to the yes category. We used Wilcoxon rank-sum tests to determine whether the average proportion of minutes the device was worn across the study period for both daytime and nighttime differed by these characteristics. All statistical analyses were conducted in R (version 4.5.1; R Foundation for Statistical Computing) [29].

Reminders

To quantify the need for automatic and manual reminders, we counted the number of participants who required no reminders to synchronize their Fitbit device, the number of participants who required only automatic reminders, and the number of participants who required both automatic and manual reminders. We counted the total number of automatic reminders sent by the reminder system and the total number of manual reminders sent by the study team over the 13-week study period, regardless of whether device synchronization occurred. To understand whether the reminders resulted in device synchronization, we also counted the number of automatic reminders that resulted in device synchronization and the number of manual reminders sent by the study team that were followed by device synchronization within the study period. Importantly, multiple manual reminders could be sent to achieve a single instance of device synchronization. When this occurred, all reminders sent during the period without synchronization were counted. We then calculated the average number of manual reminders sent when the device was synchronized within 7 days of the first manual reminder. Synchronizing within 7 days was chosen as a measure of interest because this is the approximate length of time for which the Fitbit device can store minute-level data. Although there was data loss in this time frame, we were interested in quantifying a time-sensitive measure of responsiveness to manual reminders from the study team. As the data for this study were collected during the first 13 weeks of a year-long study with ongoing data collection, synchronization events and related reminder data were excluded from the analysis of manual reminders resulting in synchronization if the time between a reminder and synchronization extended beyond the 13-week study period. These data were not removed from the total number of manual reminders sent or from the Fitbit data analysis. For example, if a reminder was sent to the participant during week 12, and the participant did not synchronize the Fitbit device until week 15, this synchronization event was excluded from the relevant analysis. All other reminders sent to the participants within the study period were included in the analysis.

Importantly, the participants were allowed to request that reminders be sent to both themselves and their parent or guardian. When a manual reminder was sent to the participant and parent or guardian using the same method, this was counted as a single manual reminder. If 2 different methods were used to contact the participant and parent or guardian, these manual reminders were counted separately. For example, if a reminder text was sent to both the participant and the parent during the same instance, this was considered a single contact. If a reminder text was sent to the participant and the parent was called, this was considered 2 separate contacts. We did this to attempt to accurately reflect the burden on the study team's time.

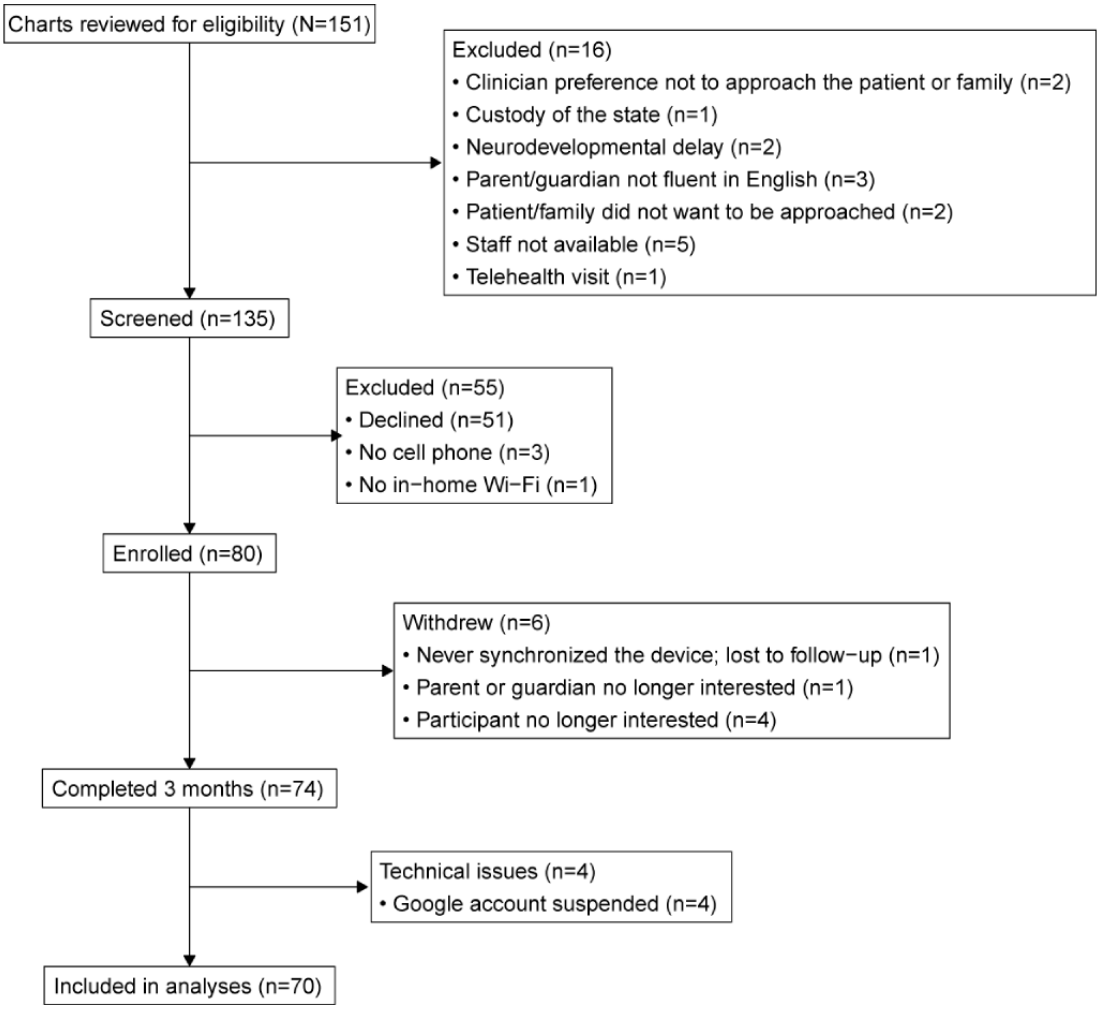
Results

Sample Characteristics

We identified 151 patients for screening from the chart review of scheduled patients with concussion (Figure 2). Of these 151 patients, 135 were screened (refer to Figure 2 for exclusion reasons). Of the 135 patients screened, 51 declined, 3 did not have access to a personal cell phone, and 1 did not have access to Wi-Fi at home. Reasons for declining included lack of interest from the patient or parent or guardian, concerns about the time commitment, being unable to wear the watch at school or work, not liking wearing a watch, already owning a smartwatch, data privacy concerns, and fear of losing or forgetting to wear the Fitbit device. Thus, 80 participants (59%) were enrolled.

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Figure 2. Flow diagram of participant screening and enrollment.



A total of 6 participants withdrew during the study period and were removed from all analyses. Due to technical problems outside the control of the study team, 4 participants' Google accounts (used to access the Fitbit app) were suspended for an extended period during the study period. When a participant's Google account was suspended, the data were not sent to the Fitbit server, and the research team was unable to access the data, despite the participant wearing the device. As this did not reflect true nonadherence, we excluded these participants from all analyses. Therefore, 70 participants were included in the analyses. Demographic and clinical characteristics are presented in Table 1.

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Table 1. Demographic and clinical characteristics.

Characteristics	Enrolled (n=80)	Included (n=70)
Age at enrollment (y), mean (SD)	15.5 (1.4)	15.5 (1.4)
Sex, n		
Male	25	20
Female	55	50
Race, n		
Asian	1	1
Black or African American	13	13
More than 1 race	12	10
White	54	46
Hispanic or Latino, n		
Yes	10	7
No	70	63
Time from injury to enrollment (days), mean (SD)	32 (31)	28 (26)
Rivermead Post-Concussion Symptoms Questionnaire score, mean (SD)	23 (12)	23 (12)
Prior mental health diagnosis, n		
Yes	42	37
Suspected	11	9
No	27	24
Prior diagnosis of attention-deficit/hyperactivity disorder, autism spectrum disorder, or specific learning disorder, n		
Yes	26	25
Suspected	7	7
No	47	38
Prior diagnosis of postural orthostatic tachycardia syndrome, n		
Yes	6	5
Suspected	2	2
No	72	63
Prior concussion, n		
None	44	39
1	15	14
2	17	13
3	3	3
4	1	1
Injury mechanism, n		
Sports related	47	40
Automobile related	14	12
Non–automobile-related fall or accident	6	5
Assault	5	5
Other	8	8

Daytime Adherence

We found that participants had adequate average daytime adherence to Fitbit device wear at all adherence thresholds across 13 weeks. Using a 50% threshold, an average of 4.4 (SD 0.8) days/wk (63%) were valid across all participants, with the highest adherence observed during the first week (6.1, SD 1.8 days; 87%). Using a 75% threshold, an average of 3.8 (SD 0.8)

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days/wk (54%) were valid across all participants, with the highest adherence during the first week (5.5, SD 2.0 days; 79%). Finally, using a 90% threshold, an average of 3.0 (SD 0.7) days/wk (43%) were valid across all participants, with the highest adherence observed during the first week (4.4, SD 2.0 days; 63%).

We found a significant effect of threshold, with both the 75% and 90% thresholds associated with significantly fewer days than the 50% threshold (both $P<.001$; Table 2). The 90% threshold was also significantly different than the 75% threshold ($\beta=-1.1$; $P<.001$). Regardless of the adherence threshold, there was a decrease in wear time across 13 weeks (Table 2; Figure 3A). With a 50% threshold, there was a decrease of 0.2 valid wear days per week across 13 weeks ($\beta=-0.2$; $P<.001$). There was no significant difference in the rate of decline across weeks between the 50% and 75% thresholds (week-by-75% threshold interaction compared to the 50% threshold: $\beta=0.005$; $P=.80$). The 90% threshold had a significantly steeper slope than both the 50% (week-by-90% threshold interaction compared to the 50% threshold: $\beta=0.05$; $P=.006$) and 75% (week-by-90% threshold interaction compared to the 75% threshold: $\beta=0.04$; $P=.02$) thresholds.

We did not find a difference in the average proportion of daytime minutes for which the device was worn across the study period between participants who participated in advanced sports and those who did not ($P=.83$). We also did not find differences in the proportion of daytime minutes for which the device was worn according to mental health ($P=.67$) or neurodevelopmental diagnoses ($P=.56$).

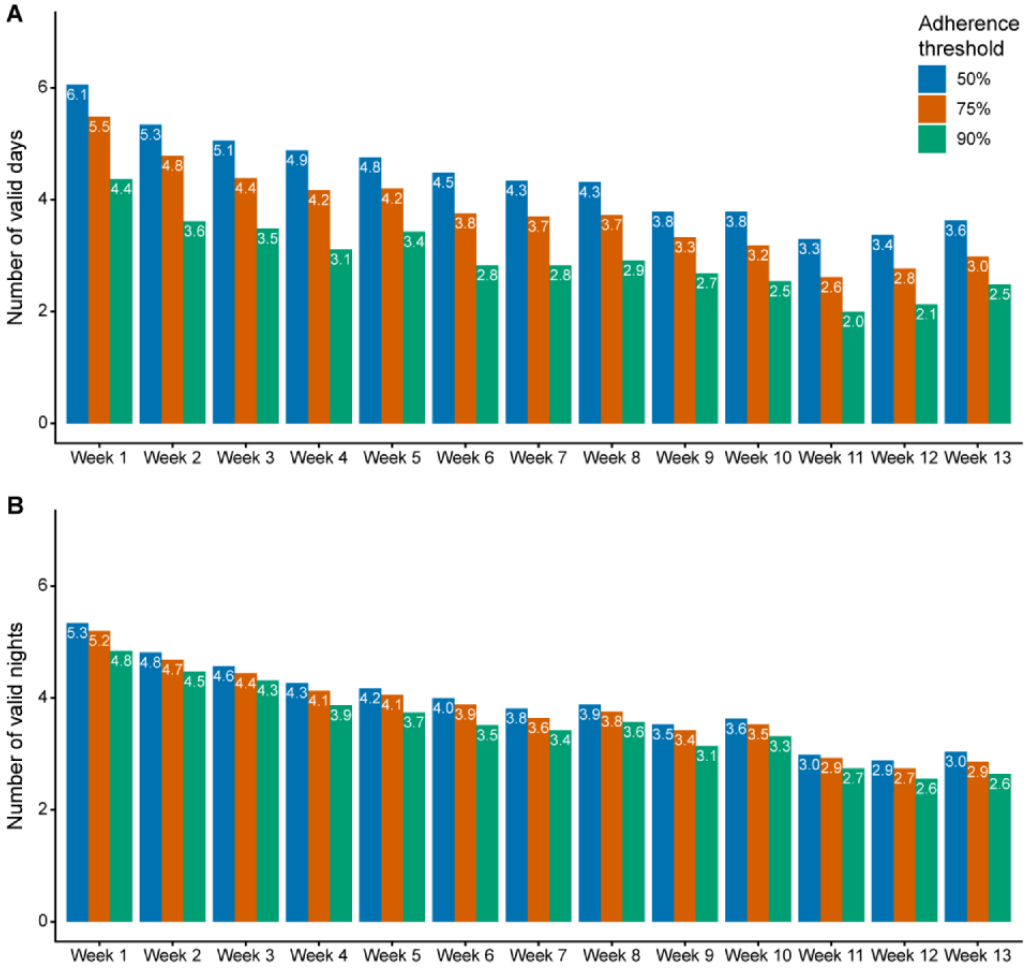
Table 2. Daytime and nighttime model results.

Model term	Estimate (β coefficient)	SE	95% CI	*P* value
Daytime model (7 AM-9:59 PM)				
Intercept	5.9	0.2	5.29 to 6.41	<.001[a]
Wk	–0.2	0.02	–0.26 to –0.16	<.001[a]
75% threshold (vs 50% threshold)	–0.7	0.1	–0.84 to –0.46	<.001[a]
90% threshold (vs 50% threshold)	–1.7	0.1	–2.02 to –1.44	<.001[a]
90% threshold (vs 75% threshold)	–1.1	0.1	–1.29 to –0.93	<.001[a]
Wk by 75% threshold (vs 50% threshold)	0.005	0.02	–0.015 to 0.026	.80
Wk by 90% threshold (vs 50% threshold)	0.05	0.02	0.02 to 0.083	.002[a]
Wk by 90% threshold (vs 75% threshold)	0.04	0.02	0.026 to 0.062	.02[a]
Nighttime model (10 PM-6:59 AM)				
Intercept	5.2	0.3	4.63 to 5.90	<.001[a]
Wk	–0.2	0.02	–0.23 to –0.14	<.001[a]
75% threshold (vs 50% threshold)	–0.1	0.1	–0.19 to –0.06	.30
90% threshold (vs 50% threshold)	–0.4	0.1	–0.52 to –0.29	.003[a]
90% threshold (vs 75% threshold)	–0.3	0.1	–0.38 to –0.19	.03[a]
Wk by 75% threshold (vs 50% threshold)	–0.00005	0.01	–0.008 to 0.008	.99
Wk by 90% threshold (vs 50% threshold)	0.008	0.01	–0.004 to 0.021	.80

[a]Significant difference at $\alpha=0.05$ level.

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Figure 3. Number of valid days and nights per week over 13 weeks using 3 different adherence thresholds. (A) Mean number of valid days per week at each threshold. (B) Mean number of valid nights per week at each threshold.



Nighttime Adherence

We found that participants had adequate average nighttime adherence to Fitbit device wear for all adherence thresholds across 13 weeks. Using a 50% threshold, an average of 3.9 (SD 0.7) nights/wk (56%) were valid across all participants, with the highest adherence observed during the first week (5.3, SD 2.1 nights; 76%). Using a 75% threshold, an average of 3.8 (SD 0.7) nights/wk (54%) were valid across all participants, with the highest adherence occurring during the first week (5.2, SD 2.1 nights; 74%). Finally, using a 90% threshold, an average of 3.6 (SD 0.7) nights/wk (51%) were valid across all participants, with the highest adherence observed during the first week (4.8, SD 2.2 nights; 69%).

We found a significant effect of threshold, with the 90% threshold associated with significantly fewer valid nights than the 50% threshold (β=–0.4; *P*<.001) and the 75% threshold (β=–0.3; *P*=.03; Table 2). Similar to daytime adherence, we found a decrease in wear time across 13 weeks regardless of the adherence threshold (week: β=–0.2; *P*<.001; Table 2; Figure 3B). However, unlike the daytime adherence, the rate of change was not significantly different between the adherence thresholds (week-by-threshold interactions: *P*>.05; Table 2; Figure 3B).

We did not find a difference in the average proportion of nighttime minutes for which the device was worn between participants who participated in advanced sports and those who did not (*P*=.68). We also did not find differences in the average proportion of nighttime minutes for which the device was worn according to mental health (*P*=.65) or neurodevelopmental diagnoses (*P*=.51).

Reminders

A total of 8 out of 70 (11.4%) participants did not require any reminders to synchronize their Fitbit device during the 13 weeks. Only automatic reminders (and no manual reminders) were required for 12 out of 70 (17.1%) participants to synchronize their Fitbit device over 13 weeks. The remaining 50 (71.4%) participants required at least 1 manual reminder from the study team to synchronize their device, in addition to the automatic reminders.

The automatic reminder system sent 338 reminders across the study period (mean 5, SD 3 per participant). Of those automatic reminders, 199 resulted in device synchronization without additional contact from the study team. In total, the study team sent 264 manual reminders (mean 4, SD 4). Of those manual reminders, 217 were sent where a subsequent device synchronization occurred during the study period (mean 3, SD 4) per participant. When the Fitbit device was synchronized within 7 days of the first manual reminder, a total of 126 manual reminders were sent (mean 2, SD 3).

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Barriers to Adherence

Participants reported various barriers to adherence. The most common barrier was trouble synchronizing the device with the Fitbit app (n=8). Other barriers included losing the Fitbit device (n=3), losing the charger (n=1), breaking the Fitbit device (n=2), forgetting account log-in information (n=1), and skin irritation (n=4).

Discussion

Principal Findings

In this study, we aimed to (1) understand adherence to device wear during the day and night using 3 different adherence thresholds in adolescents presenting for specialty concussion care and (2) define the number of reminders used to promote device wear and synchronization. We found that over 13 weeks, adolescents had average daytime adherence ranging from 3.0 to 4.4 days/wk and average nighttime adherence ranging from 3.6 to 3.9 nights/wk. For all thresholds, the highest adherence was observed during the first week (both day and night). Over the course of 13 weeks, the number of valid days and nights decreased each week, regardless of the adherence threshold used. Approximately three-quarters of the participants required at least 1 manual reminder to synchronize their device. Our results suggest that adequate adherence to Fitbit device wear can be achieved in adolescents presenting for specialty concussion care, but a reduction in device wear should be expected over time. Reminders from the study team are likely required to promote adherence.

Barriers to Enrollment

The majority of patients who were approached and eligible enrolled in the study (61.1%). Only 6 participants (7.5%) withdrew from the study during the first 13 weeks. This dropout rate is similar to that reported in previous work with adolescent athletes (10.5%) [19] and lower than that seen in similar studies with adults with chronic health conditions (approximately 20% dropout) [22]. The low dropout rate suggests that adolescents after concussion who are willing to wear a Fitbit device continue to be receptive to remote monitoring over time.

Adherence to Fitbit Device Wear

Over 13 weeks, participants had average daytime adherence ranging from 3.0 to 4.4 days/wk (42%-63%). Our daytime adherence at all thresholds was lower than the average 75% daytime adherence reported in previous work [19]. The difference in adherence rates may be partly attributable to the different populations studied. Our sample was comprised of adolescents presenting for specialty concussion care within 6 months of a diagnosed concussion from any mechanism, as opposed to adolescents receiving care in a sports medicine clinic within 10 days of a sport-related concussion [19]. Athletes with sport-related concussions may be more motivated to adhere to physiologic monitoring with consumer-grade fitness trackers [20], or motivation may change as the time since injury increases. However, we did not find a difference in adherence between participants who participated in advanced sports and those who did not. Our sample also included adolescents with comorbidities, including mental health and neurodevelopmental disorders (eg, attention-deficit/hyperactivity disorder), which may have contributed to differences in adherence [18]. However, we found no differences in adherence by these characteristics in our sample. There were also methodological differences in how adherence was defined. The daytime adherence reported in previous work required 1 heart rate data point per hour between 7 AM and 6 PM [19]. Our study required participants to wear the device for 450 to 810 minutes between 7 AM and 9:59 PM. The number of days for which the device was worn by the participants also differed between studies. Participants in Ransom et al [19] wore the device for 4 to 6 weeks after injury clearance, which ranged from 33 to 180 days (average 66 days). Therefore, most participants had fewer days of data [19] than our sample. We found that there is a decrease in adherence as time progresses regardless of the adherence threshold, which has likely contributed to our lower adherence rate over 13 weeks.

Choosing an appropriate adherence threshold is dependent on the question of interest. Using an adherence threshold that is too low for a valid day can mischaracterize activity [14] and lead to inaccurate conclusions. However, not all research questions require as high a threshold for valid wear. For example, previous work has found that the definition of valid wear time did not affect the quantification of average daily heart rate [14]. For a similar analysis of daily heart rate, a lower threshold is likely appropriate and will provide more valid days of data for the analysis. We chose to examine adherence with higher thresholds (75% and 90%) to reflect the amount of data likely needed to provide adequate physical activity [17] and sleep estimations [16]. We also included a lower threshold (50%) to explore how a less stringent requirement would affect adherence. We found that using the 75% and 90% adherence thresholds resulted in lower average adherence during both daytime and nighttime compared to a 50% adherence threshold. The 90% adherence threshold also resulted in a greater rate of reduction in daytime adherence over 13 weeks compared to the 50% and 75% thresholds.

Device Synchronization Reminders

We found that an average of 3 manual reminders were sent per participant that resulted in device synchronization, with an average of 2 manual reminders sent when participants synchronized their device within 7 days of the first manual reminder. This suggests that, to promote device wear and synchronization and optimize study personnel effort, 2 manual reminders from the study team are likely to be adequate. It is important to note that this average of 2 reminders does not include the 1 automatic reminder that was sent within this time frame (Figure 1).

A study of adults with chronic obstructive pulmonary disease and stroke found that 65% of participants required at least 1 reminder to synchronize their device over 3 months, with an average of 0.68 reminders sent per person [22]. The authors relied on an automated reminder system that sent participants text or email reminders after 5 and 12 days without synchronization [22]. When 19 days had passed without synchronization, a member of the study team followed up with the participant by phone [22]. The results of that study suggest

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that an automated reminder system is an effective tool to improve Fitbit device wear and synchronization. However, we found that 71.4% of participants in our study required a manual reminder from the study team in addition to the automatic reminders, with an average of 3 manual reminders sent by the study team. This suggests that adolescents with concussion may be less receptive to automatic reminders. It is possible that sending more automatic reminders within a shorter period (eg, 1 reminder a day for 3 days) may result in device synchronization without additional contact from the study team. Supporting this idea, previous work in adolescents with sport-related concussion contacted participants if they did not synchronize their device at least twice a week and achieved adequate adherence [19].

Even with consistent reminders to synchronize the Fitbit device, we still saw a decrease in device wear over time. Therefore, there is a need to understand how to motivate adolescents to continue to wear and synchronize their Fitbit device as time progresses. Previous work has demonstrated that habit formation [30], ease of use [21], and intrinsic motivation [31] are important factors that influence continued smart device wear.

Barriers to Adherence

Common barriers to adherence included issues synchronizing the device with the Fitbit app (n=8), skin irritation (n=4), and losing the Fitbit device (n=3). These barriers resulted in data loss because participants did not wear or synchronize the Fitbit device. To reduce noncompliance due to these issues, researchers can consider creating a synchronization troubleshooting guide, budgeting for a select number of replacement Fitbit devices, and making bands of different materials available to participants who experience skin irritation. A total of 4 participants had to be removed because their Google accounts were disabled during the study period. This occurred after Fitbit was acquired by Google, and some of the accounts used for the study were deactivated. We were able to resolve this issue, but it took several months. When using consumer-grade wearable devices, it is important for researchers to consider that there are likely to be unanticipated barriers that may affect data collection, as the technology evolves rapidly.

Potential Clinical Implementation of Fitbit Monitoring in Concussion Care

Our data demonstrate that adolescents presenting for specialty care after concussion had adequate adherence to Fitbit device wear over 13 weeks. This indicates that many patients wear the Fitbit device for sufficient periods throughout clinical recovery to provide data that could be incorporated into clinical care. Fitbit devices can provide complementary information on real-world physical activity, heart rate, and sleep that extends beyond point-in-time clinical assessments or surveys. Early physical activity is an integral component of clinical management after concussion [7,10,11]. There is evidence that self-reported physical activity does not align with actigraphy data [32]; thus, an objective measurement may provide clinicians with better insight into true activity levels. Similarly to defining adherence thresholds for research, the amount of time a patient would need to wear the Fitbit device would vary based on the information the clinician is interested in gathering. Estimating measures of daily physical activity (steps per day, minutes of moderate-to-vigorous activity, etc) will likely require a higher adherence threshold (ie, 75%) [15], whereas estimating daily resting heart rate can use a lower threshold [14], such as 50%. Using a Fitbit device to estimate sleep parameters will require the highest adherence threshold, to ensure that participants wear the device for the desired sleep window [16]. There is also an opportunity for clinicians to use the Fitbit device to understand the physiologic response to a specific activity, such as sports practice, which would not require a threshold beyond wearing the device during the activity of interest.

Limitations

Our study had a few limitations. Our sample was limited to adolescents seeking care at a specialty concussion clinic who agreed to participate in a longitudinal research study. These participants may represent a subset of adolescents with concussion who are experiencing a greater symptom burden, experiencing persisting symptoms beyond the initial days or weeks after concussion, and/or may have greater access to care [33]. Although prior work has demonstrated adequate adherence to remote monitoring in a large cohort of adolescents without concussion [34] and in adolescents with sport-related concussion and orthopedic injuries [19], future work is needed to examine the feasibility of remote monitoring in adolescents with concussion who do not present for specialty care. Importantly, our data were collected for research purposes and may not reflect the degree of adherence that would be observed if remote monitoring were occurring as part of clinical care. We acknowledge that this study is subject to selection bias and that this sample of adolescents, who agreed to participate in a 12-month research study, may not reflect the broader target patient population. Also, we defined adequate adherence as average weekly adherence of greater than or equal to 3 days. We chose this threshold based on previous work [17]; however, similar to choosing a wear time threshold, the number of valid days needed per week may differ based on the research or clinical question of interest. In addition, we tracked barriers to Fitbit device wear when participants mentioned them to a member of the study team. However, we did not perform a structured qualitative interview, which would have provided greater insight into the barriers encountered by the participants. Finally, we predefined daytime and nighttime hours for all participants. Therefore, it is possible that some participants were sleeping during daytime hours or awake during nighttime hours. This is an important consideration for studies investigating physical activity or sleep.

Conclusions

We found that over 13 weeks, adolescents presenting for specialty care after concussion had adequate adherence (defined as average adherence of greater than 3 days/wk) during both the day and night. The number of valid days and nights was highest in the first week and then decreased each week for all adherence thresholds. Approximately three-quarters of the participants required at least 1 manual reminder to synchronize their Fitbit device. This suggests that adequate adherence is expected in adolescents presenting for specialty concussion care over 13 weeks; however, a reduction in device wear is expected

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over time. Reminders from the study team are likely required to maximize adherence.

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Data Availability

The datasets generated or analyzed during this study are available from the corresponding author upon reasonable request.

Generative AI Use

The authors declare that generative AI was not used in the preparation of this manuscript.

Conflicts of Interest

None declared.

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