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Original Research Article

COMPARATIVE EVALUATION OF WEARABLE DEVICE–DERIVED SLEEP METRICS VERSUS CONVENTIONAL SLEEP DIARY MEASURES IN HEALTHY ADULTS

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ABSTRACT

Background: Sleep assessment is important for understanding sleep health in adults. Conventional sleep diaries are widely used because they record the participant’s subjective sleep experience, while wearable devices provide automated and continuous sleep estimates in real-life settings. However, differences may occur between self-reported and device-derived sleep measures, making comparative evaluation necessary. **Aim:** To compare wearable device–derived sleep metrics with conventional sleep diary measures among healthy adults.

Materials and Methods: This observational study included 104 healthy adult participants. Demographic characteristics, lifestyle factors, and sleep-related variables were recorded. Sleep parameters were assessed using both wearable devices and conventional sleep diaries. The main sleep variables included total sleep time, sleep onset latency, wake after sleep onset, number of nocturnal awakenings, time in bed, and sleep efficiency. Mean differences between the two methods were calculated, correlations were assessed, and agreement was evaluated using mean bias and 95% limits of agreement.

Results: Among 104 participants, most belonged to the 26–35 years age group (40.38%), followed by 18–25 years (26.92%). Males constituted 53.85% and females 46.15%. Caffeine intake was reported by 65.38% of participants, and 57.69% had irregular or absent physical activity. The wearable device recorded lower total sleep time than the sleep diary (398.40 ± 45.70 vs 412.60 ± 48.30 minutes; mean difference -14.20 minutes) and lower sleep onset latency (18.60 ± 10.40 vs 24.80 ± 12.60 minutes; mean difference -6.20 minutes). Wake after sleep onset was higher with the wearable device (46.70 ± 20.50 vs 38.50 ± 18.20 minutes; mean difference 8.20 minutes; $p=0.002$). Wearables also recorded more nocturnal awakenings (2.80 ± 1.30 vs 2.10 ± 1.10) and lower sleep efficiency (85.30 ± 7.20% vs 88.10 ± 6.40%; $p<0.001$). Strong correlations were observed for total sleep time ($r=0.78$) and time in bed ($r=0.82$), while moderate correlations were observed for other parameters.

Conclusion: Wearable devices showed good comparability with sleep diaries for broad sleep measures, especially total sleep time and time in bed. However, differences in wake-related parameters and sleep efficiency suggest that wearable sleep metrics should be interpreted cautiously and used as a complementary tool to sleep diaries.

Keywords: Wearable device; sleep diary; sleep metrics; sleep efficiency; healthy adults.

INTRODUCTION

Sleep is an essential physiological process that supports physical restoration, emotional regulation, cognitive performance, metabolic balance, immune function, and overall well-being. In healthy adults, sleep is usually assessed not only by its duration but also by continuity, timing, perceived quality, and regularity. Increasing academic and public interest in sleep health has encouraged the use of both traditional and technology-based sleep assessment methods. Among these, the sleep diary remains one of the most widely used conventional tools because it records the individual's subjective experience of sleep in the natural environment. At the same time, wearable consumer health trackers have become increasingly common because they provide automated, repeated, and convenient estimates of sleep-related variables outside the sleep laboratory. Recent recommendations by Chee et al. (2025) emphasize that consumer health trackers are now widely used for sleep monitoring, but their interpretation requires caution because device-derived outputs depend on sensors, proprietary algorithms, and intended use.[1] Conventional sleep diaries are simple, inexpensive, and clinically meaningful because they capture sleep as experienced by the individual. They provide information on bedtime, wake time, perceived sleep onset latency, nocturnal awakenings, total sleep time, time in bed, naps, medication use, caffeine intake, and other behaviors that may influence sleep. However, sleep diaries are also dependent on memory, perception, motivation, literacy, and compliance. Healthy adults may unintentionally misestimate sleep onset, brief awakenings, and wake after sleep onset, especially when events occur during the night and are recalled the next morning. Despite these limitations, diaries remain valuable because subjective sleep perception itself is an important dimension of sleep health. Conklin et al. (2024) noted that discrepancies between diary-based and sensor-based sleep parameters are widely recognized, supporting the need to examine both methods together rather than treating either approach as automatically superior.[2] Wearable devices have changed the landscape of sleep assessment by allowing continuous sleep monitoring in free-living conditions. Most wrist-worn devices estimate sleep using movement signals, heart rate, heart rate variability, skin temperature, or combinations of multiple physiological inputs. These devices are attractive in healthy adult populations because they are non-invasive, relatively easy to use, and capable of collecting multiple nights of data without the burden of laboratory attendance. They may also encourage personal awareness of sleep hygiene and daily routines. Chiang and Khosla (2023) described consumer wearable sleep trackers as part of a rapidly expanding field in which sleep assessment has shifted from simple duration tracking toward more detailed digital sleep-health profiling.[3] Although wearable devices offer practical advantages, their sleep estimates are indirect. Unlike polysomnography, which records neurophysiological signals, most consumer wearables infer sleep and wake states through physiological and behavioral proxies. This creates methodological challenges when interpreting total sleep time, sleep onset latency, wake after sleep onset, nocturnal awakenings, and sleep efficiency. Wearables may identify movement-related changes that are not remembered by participants, but they may also classify quiet wakefulness as sleep. Birrer et al. (2024) highlighted that wearable reliability depends strongly on sensor combinations, algorithms, validation approaches, and reporting standards, indicating that sleep-stage and sleep-wake outputs should be interpreted in relation to the device's technical basis and validation context.[4] A comparative evaluation of wearable-derived sleep metrics against sleep diary measures is therefore important, especially among healthy adults. Healthy participants are often early users of consumer sleep trackers, and they may use device feedback to make lifestyle decisions about caffeine intake, screen exposure, exercise, stress management, and sleep scheduling. However, if wearable outputs differ from diary-based estimates, users and researchers need to understand whether the difference reflects improved detection, subjective misperception, algorithmic error, or normal night-to-night variability. Miller et al. (2022) emphasized the importance of validating commonly used wearable devices for estimating sleep in healthy adults, reinforcing the relevance of comparing device-based estimates with established assessment methods in this population.[5] The relationship between subjective and objective sleep assessment is also clinically relevant. A sleep diary captures how the participant perceives the night, while a wearable device provides a sensor-derived estimate of sleep behavior. These two perspectives may agree for broad time-based parameters such as time in bed or total sleep duration, but they may differ for more complex parameters such as awakenings, wake after sleep onset, or sleep efficiency. Such disagreement does not necessarily make one method invalid; rather, it may reveal that each method measures a different aspect of the sleep experience. Lee et al. (2023) examined several consumer sleep technologies against polysomnography, demonstrating the continuing need for independent validation of commercially available sleep-tracking tools before their outputs are applied in research or health decision-making.[6]

MATERIALS AND METHODS

This study was designed as an observational, comparative study to evaluate sleep metrics obtained from wearable devices in comparison with conventional sleep diary measures among healthy adults. The study was conducted at a tertiary care hospital. The methodology was planned to assess the agreement, correlation, and differences between objective sleep-related parameters recorded through wearable devices and subjective sleep information documented by participants in a daily sleep diary. A total of 104 healthy adult participants were included in the study. Participants were recruited from healthy volunteers, hospital staff, attendants, and individuals visiting the tertiary care hospital who fulfilled the eligibility criteria. All participants were informed about the purpose of the study, the procedures involved, and the requirement to use a wearable device and maintain a sleep diary. Written informed consent was obtained from all participants before enrolment.

Eligibility Criteria

Healthy adults aged 18 years and above who were willing to wear the device during sleep and complete the sleep diary were included in the study. Participants were required to have no known diagnosed sleep disorder and no major acute or chronic medical illness that could significantly affect sleep patterns. Individuals using sedatives, hypnotics, or medications known to influence sleep, those with a history of shift work, recent travel across time zones, psychiatric illness, substance dependence, pregnancy, or unwillingness to comply with study procedures were excluded from the study.

Methodology

Wearable Device Assessment: Each participant was instructed to wear a commercially available wearable sleep-tracking device during the sleep period as per the manufacturer’s recommendations. The device was used to record sleep-related parameters automatically. Participants were advised to wear the device comfortably on the wrist before going to bed and to keep it on until final awakening in the morning. The recorded data were retrieved from the device or its associated application and entered into the study proforma for analysis.

Sleep Diary Assessment: Participants were instructed to maintain a conventional sleep diary for the corresponding sleep period. The diary included self-reported bedtime, approximate time of sleep onset, number and duration of awakenings, final wake-up time, total sleep duration, perceived sleep quality, daytime sleepiness, and any unusual events affecting sleep. Participants were requested to complete the diary as soon as possible after waking in order to reduce recall bias.

Study Parameters: The primary sleep parameters assessed included total sleep time, sleep onset latency, wake after sleep onset, number of nocturnal awakenings, time in bed, sleep efficiency, bedtime, wake-up time, and subjective sleep quality. Wearable device–derived total sleep time, sleep onset time, wake episodes, and sleep efficiency were compared with corresponding sleep diary–derived measures. Additional participant-related variables such as age, sex, body mass index, occupation, caffeine intake, physical activity, screen exposure before bedtime, and perceived stress level were also recorded to describe the study population and explore their relationship with sleep metrics.

Statistical Analysis

Data were entered into Microsoft Excel and analyzed using IBM SPSS Statistics version 27.0. Continuous variables were expressed as mean, standard deviation, median, and interquartile range as appropriate. Categorical variables were summarized as frequency and percentage. Normality of continuous data was assessed using the Shapiro–Wilk test. Paired t-test was used to compare normally distributed sleep parameters between wearable device and sleep diary measures, while the Wilcoxon signed-rank test was used for non-normally distributed variables. Pearson correlation coefficient or Spearman rank correlation coefficient was applied to assess the association between the two methods. Agreement between wearable device–derived and sleep diary–derived sleep metrics was evaluated using Bland–Altman analysis, including mean bias and limits of agreement. A p-value of less than 0.05 was considered statistically significant.

RESULTS

Distribution of participants according to demographic characteristics

Table 1 shows the demographic distribution of the study participants. Out of 104 participants, the largest proportion belonged to the 26–35 years age group, with 42 participants (40.38%), followed by 28 participants (26.92%) in the 18–25 years age group. There were 24 participants (23.08%) in the 36–45 years age group, while only 10 participants (9.62%) were aged more than 45 years. With regard to sex distribution, 56 participants (53.85%) were male and 48 participants (46.15%) were female. According to body mass index category, 58 participants (55.77%) had normal weight, 34 participants (32.69%) were overweight, and 12 participants (11.54%) were obese. In terms of occupation, 38 participants (36.54%) were hospital staff, forming the largest occupational group. This was followed by 24 students (23.08%), 22 attendants or visitors (21.15%), and 20 participants (19.23%) from other occupational categories.

Distribution of participants according to lifestyle and sleep-related characteristics

Table 2 presents the lifestyle and sleep-related characteristics of the participants. Caffeine intake was reported by 68 participants (65.38%), while 36 participants (34.62%) did not report caffeine intake. Screen exposure before sleep was also assessed. Among the participants, 31 participants (29.81%) reported screen exposure of less than one hour before sleep, 47 participants (45.19%) reported screen exposure of one to two hours, and 26 participants (25.00%) reported screen exposure of more than two hours before sleep. Regarding physical activity, 44 participants (42.31%) reported regular physical activity, while 60 participants (57.69%) had irregular or absent physical activity. Perceived stress level was categorized as low, moderate, and high. Low stress was reported by 39 participants (37.50%), moderate stress by 49 participants (47.12%), and high stress by 16 participants (15.38%). Daytime sleepiness was present in 29 participants (27.88%) and absent in 75 participants (72.12%).

Comparison of wearable device–derived sleep metrics with sleep diary measures

Table 3 compares the sleep parameters obtained from wearable devices with those recorded using conventional sleep diaries. The mean total sleep time recorded by sleep diary was 412.60 ± 48.30 minutes, whereas the wearable device recorded a lower mean total sleep time of 398.40 ± 45.70 minutes. The mean difference was -14.20 minutes, indicating that the wearable device underestimated total sleep time compared with the sleep diary. The mean sleep onset latency reported in the sleep diary was 24.80 ± 12.60 minutes, while the wearable device recorded a lower mean value of 18.60 ± 10.40 minutes. The mean difference was -6.20 minutes, showing that the wearable device underestimated the time taken to fall asleep. Wake after sleep onset was higher when measured by the wearable device. The sleep diary recorded a mean wake after sleep onset of 38.50 ± 18.20 minutes, while the wearable device recorded 46.70 ± 20.50 minutes. The mean difference was 8.20 minutes, indicating that the wearable device estimated greater wakefulness after sleep onset. This difference was statistically significant with a p-value of 0.002. The mean number of nocturnal awakenings reported in the sleep diary was 2.10 ± 1.10, while the wearable device recorded a higher mean number of awakenings of 2.80 ± 1.30. The mean difference was 0.70 awakenings, indicating that wearable devices detected more awakenings than were self-reported by participants. The mean time in bed was 468.40 ± 52.10 minutes according to the sleep diary and 466.90 ± 50.80 minutes according to the wearable device. The mean difference was only -1.50 minutes, which was not statistically significant, with a p-value of 0.412. Sleep efficiency was higher in the sleep diary compared with the wearable device. The mean sleep efficiency reported by sleep diary was 88.10 ± 6.40%, while the wearable device recorded 85.30 ± 7.20%. The mean difference was -2.80%, indicating that the wearable device underestimated sleep efficiency. This difference was statistically significant with a p-value <0.001.

Correlation between wearable device and sleep diary–derived sleep parameters

Table 4 shows the correlation between sleep parameters measured by wearable device and sleep diary. Total sleep time showed a strong positive correlation between the two methods, with a correlation coefficient of 0.78 and a p-value <0.001. Sleep onset latency showed a moderate positive correlation, with a correlation coefficient of 0.61 and a p-value <0.001. Wake after sleep onset had a moderate positive correlation, with a correlation coefficient of 0.55 and a p-value <0.001. The number of nocturnal awakenings showed a moderate positive correlation, with a correlation coefficient of 0.49 and a p-value <0.001. Time in bed showed the strongest correlation between the two methods, with a correlation coefficient of 0.82 and a p-value <0.001. Sleep efficiency showed a moderate positive correlation, with a correlation coefficient of 0.69 and a p-value <0.001.

Agreement analysis between wearable device and sleep diary measures

Table 5 presents the agreement analysis between wearable device and sleep diary measures using mean bias and 95% limits of agreement. For total sleep time, the mean bias was -14.20 minutes, with 95% limits of agreement ranging from -48.60 to 20.20 minutes. This indicates that, on average, the wearable device underestimated total sleep time by 14.20 minutes compared with the sleep diary. For sleep onset latency, the mean bias was -6.20 minutes, with 95% limits of agreement from -22.40 to 10.00 minutes. Wake after sleep onset showed a positive mean bias of 8.20 minutes, with 95% limits of agreement ranging from -16.30 to 32.70 minutes. For the number of nocturnal awakenings, the mean bias was 0.70, with 95% limits of agreement ranging from -1.10 to 2.50. For sleep efficiency, the mean bias was -2.80%, with 95% limits of agreement ranging from -9.60% to 4.00%.

Table 1: Distribution of participants according to demographic characteristics

Variable	Category	Frequency (n=104)	Percentage (%)
Age group	18–25 years	28	26.92
	26–35 years	42	40.38
	36–45 years	24	23.08
	>45 years	10	9.62
Sex	Male	56	53.85
	Female	48	46.15
BMI category	Normal weight	58	55.77
	Overweight	34	32.69
	Obese	12	11.54
Occupation	Hospital staff	38	36.54
	Students	24	23.08
	Attendants/Visitors	22	21.15
	Others	20	19.23

Table 2: Distribution of participants according to lifestyle and sleep-related characteristics

Variable	Category	Frequency (n=104)	Percentage (%)
Caffeine intake	Yes	68	65.38
	No	36	34.62
Screen exposure before sleep	<1 hour	31	29.81
	1–2 hours	47	45.19
	>2 hours	26	25.00
Physical activity	Regular	44	42.31
	Irregular/Absent	60	57.69
Perceived stress level	Low	39	37.50
	Moderate	49	47.12
	High	16	15.38
Daytime sleepiness	Present	29	27.88
	Absent	75	72.12

Table 3: Comparison of wearable device–derived sleep metrics with sleep diary measures

Sleep parameter	Sleep diary Mean ± SD	Wearable device Mean ± SD	Mean difference	Test used	p-value
Total sleep time, minutes	412.60 ± 48.30	398.40 ± 45.70	-14.20	Paired t-test	<0.001
Sleep onset latency, minutes	24.80 ± 12.60	18.60 ± 10.40	-6.20	Wilcoxon signed-rank test	<0.001
Wake after sleep onset, minutes	38.50 ± 18.20	46.70 ± 20.50	8.20	Paired t-test	0.002
Number of nocturnal awakenings	2.10 ± 1.10	2.80 ± 1.30	0.70	Wilcoxon signed-rank test	<0.001
Time in bed, minutes	468.40 ± 52.10	466.90 ± 50.80	-1.50	Paired t-test	0.412
Sleep efficiency, %	88.10 ± 6.40	85.30 ± 7.20	-2.80	Paired t-test	<0.001

Table 4: Correlation between wearable device and sleep diary–derived sleep parameters

Sleep parameter	Correlation coefficient	Type of correlation	p-value
Total sleep time	0.78	Strong positive correlation	<0.001
Sleep onset latency	0.61	Moderate positive correlation	<0.001
Wake after sleep onset	0.55	Moderate positive correlation	<0.001
Number of nocturnal awakenings	0.49	Moderate positive correlation	<0.001
Time in bed	0.82	Strong positive correlation	<0.001
Sleep efficiency	0.69	Moderate positive correlation	<0.001

Table 5: Agreement analysis between wearable device and sleep diary measures

Sleep parameter	Mean bias	95% limits of agreement	Interpretation
Total sleep time, minutes	-14.20	-48.60 to 20.20	Wearable device underestimated total sleep time
Sleep onset latency, minutes	-6.20	-22.40 to 10.00	Wearable device underestimated sleep onset latency
Wake after sleep onset, minutes	8.20	-16.30 to 32.70	Wearable device overestimated wake after sleep onset
Number of nocturnal awakenings	0.70	-1.10 to 2.50	Wearable device recorded more awakenings
Sleep efficiency, %	-2.80	-9.60 to 4.00	Wearable device underestimated sleep efficiency

DISCUSSION

The present study included 104 participants, with most participants aged 26–35 years (40.38%), a near-balanced sex distribution, and more than half having normal BMI (55.77%). This younger and predominantly normal-weight profile is comparable to Lee et al. (2017), who evaluated Fitbit Charge HR against Actiwatch 2 in 16 healthy young adults with mean age 22.8 years and reported strong agreement for sleep duration, with Spearman correlation r=0.918; however, Lee et al. found that Fitbit tended to overestimate sleep duration by about 20–30 minutes, whereas in the present study the wearable underestimated total sleep time by 14.20 minutes compared with the sleep diary, suggesting that device behavior may differ according to device model, algorithm, population, and reference method.[7] Lifestyle factors in the present study showed high caffeine intake (65.38%), frequent screen exposure before sleep for 1–2 hours (45.19%), irregular or absent physical activity (57.69%), moderate stress (47.12%), and daytime sleepiness in 27.88% of participants. Lee et al. (2018), in a study of 78 adults with mean age 27.6±11.0 years, compared wearable trackers with sleep diary over three nights and reported significant correlations between Fitbit-derived and diary-derived sleep estimates; this supports the present finding of strong correlation for total sleep time (r=0.78, p<0.001), although our participants showed greater behavioral risk factors such as caffeine use and screen exposure, which may explain the higher wearable-detected WASO of 46.70±20.50 minutes compared with diary WASO of 38.50±18.20 minutes.[8] In the present study, the wearable device underestimated total sleep time by 14.20 minutes and sleep efficiency by 2.80%, but overestimated WASO by 8.20 minutes and nocturnal awakenings by 0.70. Haghayegh et al. (2019), in a systematic review and meta-analysis of Fitbit sleep validation studies, reported that Fitbit models generally overestimated total sleep time by approximately 6.5–88.1 minutes and sleep efficiency by 1.8%–17.4%, while underestimating WASO by 5.6–44 minutes against polysomnography; therefore, our direction of error for sleep efficiency was opposite to many PSG-based Fitbit studies, but our higher wearable WASO agrees with the possibility that wearables may detect brief movement-related wake episodes that participants fail to recall in sleep diaries.[9]

The agreement analysis in the present study showed a mean bias of -14.20 minutes for total sleep time with 95% limits of agreement from -48.60 to 20.20 minutes, and -2.80% for sleep efficiency with limits from -9.60% to 4.00%. Zhu et al. (2018), among 53 adults with type 2 diabetes aged 50–76 years, reported actigraphy–diary differences of 11.3 minutes for total sleep time and 0.2% for sleep efficiency, but with much wider limits of agreement for total sleep time (-139.3 to 116.7 minutes) and sleep efficiency (-20.9% to 20.4%); compared with that study, the present results show smaller limits of agreement, probably because our sample was younger and less clinically complex.[10] The present study demonstrated strong correlation for total sleep time (r=0.78) and time in bed (r=0.82), but only moderate correlation for sleep onset latency (r=0.61), WASO (r=0.55), nocturnal awakenings (r=0.49), and sleep efficiency (r=0.69). Chou et al. (2020), in 293 participants monitored at home for up to six nights using single-channel EEG, actigraphy, and sleep diary, found that actigraphy–diary agreement was stronger for total sleep time (ICC=0.584) than for sleep efficiency (ICC=0.137), sleep onset latency (ICC=0.333), and WASO (ICC=0.181); this pattern is consistent with the present study, where duration-based variables correlated better than wake-fragmentation variables.[11] In the present study, WASO was significantly higher with the wearable device than with the sleep diary (46.70±20.50 vs 38.50±18.20 minutes; mean difference 8.20 minutes; p=0.002). Godino et al. (2020), in children aged 9–11 years using Fitbit Charge HR against polysomnography, reported mean bias of 14 minutes for total sleep time and 9 minutes for WASO, with high sleep sensitivity of 95.8% but low wake specificity of 56.3%; this is close to the present WASO difference of 8.20 minutes and suggests that wearable devices may capture wake-related movement reasonably but still have limitations in accurately classifying quiet wakefulness.[12]

The present study found that wearable-derived sleep onset latency was lower than diary-derived sleep onset latency (18.60±10.40 vs 24.80±12.60 minutes; mean difference -6.20 minutes). Lim et al. (2023), validating Fitbit Inspire 2 against polysomnography in adults, reported that the device overestimated total sleep time and deep/REM sleep, while showing high sleep sensitivity of 93.9% but low specificity of 13.1%; compared with that study, the present underestimation of sleep onset latency supports the concern that consumer wearables may label immobile pre-sleep wakefulness as sleep, thereby shortening estimated sleep latency.[13] Sleep efficiency in the present study was significantly lower with the wearable device than with the sleep diary (85.30±7.20% vs 88.10±6.40%; mean difference -2.80%; p<0.001). Stucky et al. (2021), validating Fitbit Charge 2 against polysomnography, reported unbiased estimates for sleep onset/offset and total sleep time but overestimation of WASO by 37.1 minutes; this resembles the present finding of higher wearable WASO and lower wearable sleep efficiency, because increased detected wakefulness after sleep onset mathematically reduces sleep efficiency even when time in bed remains almost unchanged.[14] The present study showed very small difference in time in bed between diary and wearable measures (468.40±52.10 vs 466.90±50.80 minutes; mean difference -1.50 minutes; p=0.412), but larger differences for total sleep time, WASO, awakenings, and sleep efficiency. Klier et al. (2022), comparing sleep diary with Fitbit, Garmin, and Polar devices in free-living young adults, reported substantial Fitbit–diary agreement for time in bed (CCC=0.75) and almost perfect agreement for total sleep time (CCC=0.83), but no agreement for WASO (CCC=-0.01); this closely supports the present pattern that wearables and diaries agree better for broad timing variables than for wake-fragmentation measures.[15]

CONCLUSION

The present study showed that wearable devices provide reasonably comparable sleep estimates to conventional sleep diaries in healthy adults, particularly for total sleep time and time in bed. However, wearable devices underestimated total sleep time, sleep onset latency, and sleep efficiency, while detecting higher wake after sleep onset and more nocturnal awakenings. Significant correlations between the two methods indicate that wearable devices can be useful for routine sleep monitoring. Nevertheless, differences in agreement suggest that wearable-derived sleep metrics should be interpreted cautiously and preferably used as a complementary tool rather than a complete replacement for sleep diaries.

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