Improving Sleep Health Through The Design Of Smartwatch-Based Self-Tracking With Self-Regulation Techniques

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Abstract. Sleep-related problems are increasingly prevalent in the world and can seriously affect people's health and life. Meanwhile, smartwatch-based self-tracking holds great promise for empowering individuals to manage and improve their sleep health, yet there is a lack of understanding on the effects of self-tracking on user attitudes and behaviors, as well as optimized design strategies that can motivate real behavioral change. This study investigated the sleep data of users for two weeks in the field through smartwatch-based self-tracking, and analyzed their behaviors, preferences and needs related to the process, which provided the empirical basis for smart design solutions incorporating self-regulation techniques. Results suggested that sleep self-tracking can increase health awareness and promote behavioral adjustments, but the self-tracking process and data presentation need to be improved, such as setting clear goals, mining valuable information behind the data and providing useful feedback. Therefore, we proposed optimization and visualization strategies, by combining self-regulation techniques and user-centered perspectives to improve the design of smartwatch-based sleep self-tracking.

Keywords-self-tracking; smart design; sleep health; self-regulation

1. Introduction

Following the COVID-19 outbreak, negative changes to people's sleep patterns and quality have been noticed globally [1]. In China, according to the latest China Sleep Research Report 2023 [2], nearly half of the respondents have sleep-related problems and potential sleep disorders, which can seriously affect their health and life. Meanwhile, with the development of digital media technologies for conveniently collecting and sharing physical health data (such as wearables), self-tracking or the "Quantified Self", holds great promise for empowering individuals to manage and improve their health [3] [4]. It was found in several studies that self-tracking technology allowed for a better understanding of one's body and a sense of security [5]. Smartwatches, an increasingly popular wearable device with various functions, might further contribute to the effectiveness of health self-tracking, particularly in the area of sleep monitoring.

Unlike medical monitoring devices normally required for assessing sleep-related problems in hospitals, smartwatches provide an alternative way in daily life to track sleep activities based on continuous, real-time updated physiological data such as body temperature, heart rate, blood pressure, and blood oxygen [6] [7]. With direct access to these personal health statistics [8],

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users wearing smart tracking devices were able to pay more attention to their physical health [9] and improved health capabilities for better preventing from or detecting health problems [10].

In recent years, the field of human-computer interaction and computing has seen an influx of self-tracking studies related to sleep issues, such as sleep hygiene advice [11], monitoring sleep [12], environmental disturbances [13], and sharing sleep data with others [14]. Although wearable devices are growing rapidly in the field of Consumer Sleep Technology (CST) [15], there is still a lack of understanding on the effect of self-tracking on actual user attitudes and behaviors, particularly regarding the usefulness of sleep data for changing sleep behaviors and improving sleep outcomes. From the design perspective, based on the well-established theory of self-regulation [16], goal-setting, tracking and feedback as the three key components required for behavioral change, should be incorporated to optimize the design of sleep self-tracking for better motivating desired sleep behaviors.

This study sought to understand how people perceive sleep health information tracked by smartwatches, including their attitudes and preferences towards sleep self-tracking, as well as real experiences of using a self-tracking application in the field for two weeks. Design considerations related to self-regulation techniques were investigated in order to improve upon the user experience of tracking sleep and more important, to promote healthier sleep. We also analyzed users' sleep behavioral metrics during the two weeks and explored the impact of self-tracking on actual sleep behaviors. Such findings will contribute to theoretical knowledge about self-tracking with self-regulation components incorporated, and help improve design of the self-tracking process in the sleep domain.

2. Methods

2.1 Procedures

In this study, detailed two-week sleep data in the field were collected by Huawei Watch 3, one of the leading smartwatches in the Chinese market, through its advanced TruSleep 3.0 technology for monitoring and measuring sleep, which allows for accurate recording of sleep staging structures and provides multiple parameters for assessing sleep quality [17]. Obtained data from each individual participant at each night included the following: time falling asleep, sleep duration, deep sleep duration, light sleep duration, rapid eye movement (REM) duration, percentage of deep sleep, percentage of light sleep, percentage of rapid eye movement, incidences of wakefulness, deep sleep continuity score, respiratory quality score, as well as an overall sleep score. The overall sleep score was calculated by the TruSleep 3.0 technology based on a synthesis of core indicators such as overall sleep duration, sleep efficiency, and durations of stages (i.e., light sleep/deep sleep/REM sleep) [17]. When the field data collection ended, semi-structured one-on-one in-depth interviews were also conducted to collect users' individual sleep conditions and the extent of their sleep problems as well as their feelings of use, satisfaction, usage and needs when using smartwatches for sleep monitoring. The interview protocol consisted of the following three parts: (1) to understand participants' sleep status as well as sleep-related problems and disturbances; (2) to investigate satisfaction, usage and feelings of the participants about monitoring sleep with smartwatches; and (3) to explore the data of interest and expectations of users for sleep self-tracking applications.

2.2 Sample and data analysis

This study focused on smartwatch users aged 18-25 years old, so eight smartwatch users born between 1998 and 2001 were invited to participate. Each participant was given a Huawei Watch 3 and required to wear it in daily life for 14 days consecutively, as well as uploading sleep data from the previous night every morning through an online spreadsheet, to be processed and analyzed by the researchers with statistical software SPSS. The follow-up one-on-one interviews were conducted using teleconferencing software, and each interview lasted 30 to 40 minutes. With the consent of the interviewees, we audio-recorded these interviews, converted them into written notes and analyzed with Atlas.t software, which included coding and categorizing the information from the interview transcripts and ranking the number of codes in each section.

3. Results and discussion

3.1 Current sleep status and habits

Participants' specific sleep time is affected by their daily life and study schedule, indicating that their sleep habits are relatively less regular. All participants would like to get 7 to 8 hours of sleep per night, with the majority (n=7) wishing to be able to fall asleep within 15 minutes before midnight, yet nearly half of them were not able to meet their goals as shown in Figure 1. Figure 2 also displayed the average length of deep sleep for each participant.

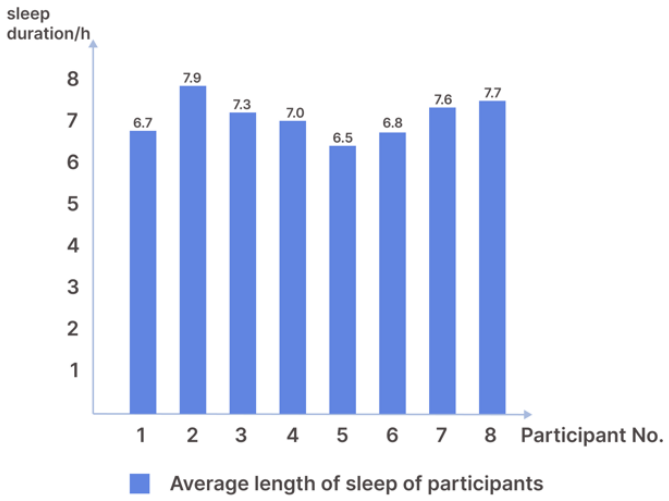

Figure 1. Mean sleep duration

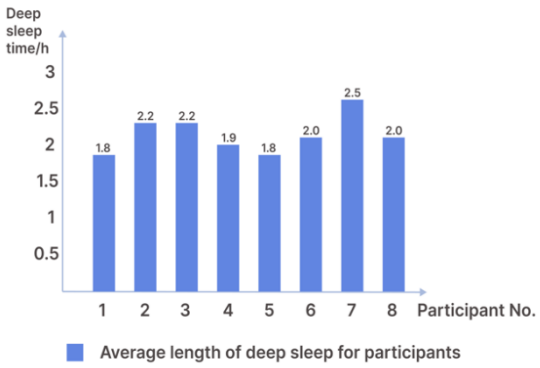

Figure 2. Mean deep sleep time

3.2 Preferences for sleep self-tracking data

Of the 12 data items presented by the sleep self-tracking application, participants cared most about sleep duration (including the percentage of deep sleep, light sleep, and wakefulness), time to sleep, and sleep quality scores. The sleep duration data helped them understand the quality and structure of their sleep, and may have influenced whether they needed a lunch break and how they organized their activities and studies for the day. Time to sleep was also important for the respondents to plan subsequent activities for the next day.

In addition, the majority of the participants (n=6) were interested in scoring sleep quality and would use the sleep scores as a reference to assess their own sleep performance. The sleep score was calculated based on a synthesis of sleep duration, sleep efficiency, light sleep duration, deep sleep duration and REM sleep duration, which served as an indicator of overall sleep quality. As shown in Figure 3, the average sleep score of most participants (n=7) was between 75 and 80, indicating an acceptable performance to be further improved. On the other hand, Figure 4 displayed two examples of variations among the scores during the two weeks, suggesting the vulnerability of sleep quality among the participants and the needs to stabilize it in the long run.

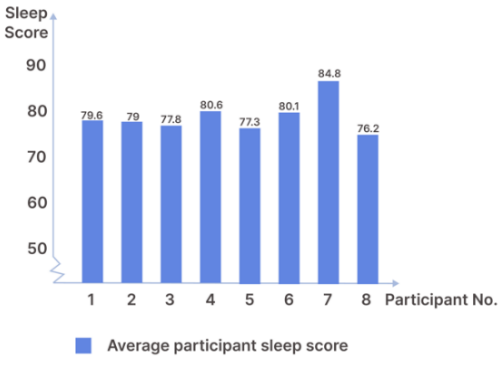

Figure 3. Mean sleep score

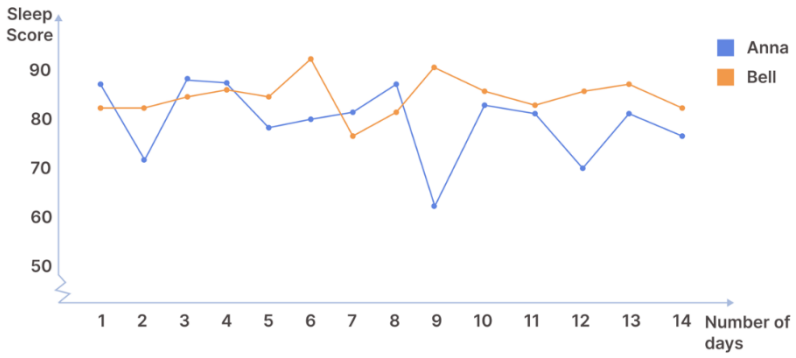

Figure 4. Change in sleep score over two weeks

3.3 Satisfaction with use of smartwatch-based sleep self-tracking

Participants were able to quickly familiarize themselves with the use of smartwatch sleep monitoring, and Figure 5 indicates the main sources of satisfaction: (1) Monitoring sleep-related data helped participants better understand the previous night's sleep, which provided a basic macro-awareness of their own sleep and helped better control their sleep conditions; (2) If they slept late the night before, they might try to go to sleep earlier that night, suggesting that the data helped them adjust their sleep behavior; (3) Sharing sleep status data with friends can increase social conversations and may improve communication by comparing data with friends.

We also found the main factors that made participants dissatisfied, as shown in Figure 6: (1) dissatisfaction with the use of the smartwatch device, which includes poor range, uncomfortable wearing and participants' allergic reactions; (2) dissatisfaction with data presentation, in which the data were difficult to understand with too much detail and there were doubts about the accuracy of monitoring; (3) causing negative emotions, e.g., seeing unsatisfactory sleep data from the previous night can cause negative emotions.

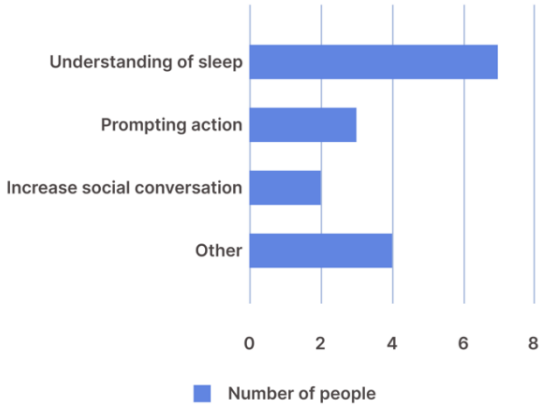

Figure 5. Reasons why participants were satisfied with smartwatch sleep monitoring

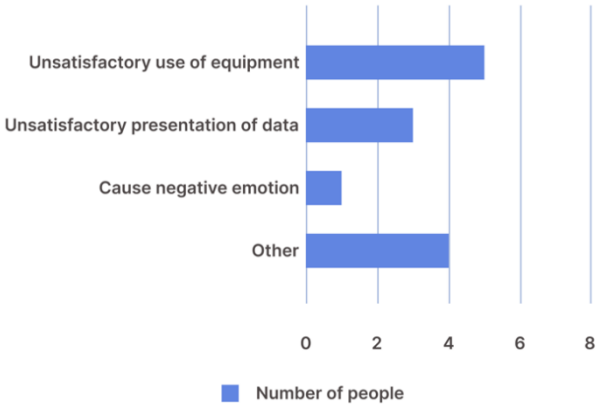

Figure 6. Reasons why participants were dissatisfied with smartwatch sleep monitoring

Overall, the majority of participants (n=6) were positive about the data, believing it helped improve sleep behavior, whereas some participants (n=2) also felt that the use of smartwatch sleep monitoring could be stressful or cognitively taxing. Therefore, using smartwatches as a medium for sleep monitoring will bring a new experience, but attention also needs to be paid to the design of smartwatch sleep data presentation and interface design.

3.4 Design improvements needed

All participants indicated that they used the watch to monitor their sleep in order to understand their sleeping habits. The recording effect of the data was helpful in understanding their sleep condition, and the information behind the data reflecting lifestyle habits and potential health hazards can indirectly change their sleep health awareness. However, in order to lead to actual behavioral changes, clear goals must be set up before the self-tracking process, and accurate feedback should be provided constantly to ensure the effectiveness of self-tracking. Participants expected more interesting designs for smartwatch sleep self-tracking applications, and also needed more sleep data analysis to better understand their sleep habits. Such improvements will better motivate them to take positive actions to improve sleep and daytime performance. Although respondents used self-tracking in slightly different ways with slightly different frequencies, all agreed that the data was crucial for better managing their lives.

4. Design optimization

Based on the empirical results, we proposed the following design scheme that incorporated self-regulation techniques, as shown in Figure 7. Three modules were set up representing the three key components of the self-regulation theory, i.e., goal setting, monitoring and feedback. First of all, the goal setting page allows the users to set up sleep goals (e.g., sleep onset, total duration), and also provides a convenient alarm setting function. Then, with the sleep data gathered from smartwatch-based monitoring, the feedback module can smartly process them and visualize different components of sleep such as duration of deep sleep, light sleep and rapid eye

movement (REM) sleep, which helps users understand particular patterns and trends related to their sleep health. An interface is also provided for displaying achievement rewards for attaining specific sleep goals. In addition, when the user wakes up every morning, he/she also needs to do a subjective assessment of last night's sleep quality, to be combined with objective monitoring data for further analysis and presentation.

Figure 7. Design modules of smartwatch-based sleep self-tracking

5. Conclusions

This study investigated the sleep data of smartwatch users in the field for the duration of two weeks, and analyzed their needs for improving the design of smartwatch-based sleep self-tracking. It was found that sleep self-tracking can help users understand their sleep conditions and motivate behavioral adjustments. On the other hand, there is much room for design improvements regarding the self-tracking process and data presentation, since sleep data are difficult to understand and too much detail in the data increases the cognitive burden of users. Such problems can be addressed by incorporating effective self-regulation techniques with goal setting and feedback [16]. Results of this study also confirmed the need for combining objective data and users' subjective feelings as a more comprehensive form of self-tracking in the sleep domain [18]. Based on our empirical research, therefore, we proposed optimized design and visualization strategies, by combining self-regulation techniques and user-centered perspectives to improve the design of smartwatch-based sleep self-tracking. Findings of this study also lay the foundation for further experimental research to evaluate effectiveness of such strategies in the field.

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References

[1] Yin, J., Xu, J., & Ren, T. L. (2023) Recent Progress in Long-Term Sleep Monitoring Technology.*Biosensors*, **13(3),** 395.

[2] China Sleep Research Society 2023. Research Center of Social Psychology.http://www.zgsmyjh.org/.

[3] Cartwright, L. (1995) Screening the body: Tracing medicine's visual culture. U of Minnesota Press. Minnesota .

[4] Lupton, D. (2016) Towards critical digital health studies: Reflections on two decades of research in health and the way forward. *Health,* **20(1)**: 49-61.
[5] Hortensius, J., Kars, M. C., Wierenga, W. S., Kleefstra, N., Bilo, H. J., & van der Bijl, J. J. (2012) Perspectives of patients with type 1 or insulin-treated type 2 diabetes on self-monitoring of blood glucose: a qualitative study. *BMC Public Health,* **12(1)**: 1-11.
[6] Ogbanufe, O., & Gerhart, N. (2018) Watch it! Factors driving continued feature use of the smartwatch. *International Journal of Human–Computer Interaction,* **34(11)**: 999-1014.
[7] Verplanken, B., & Wood, W. (2006) Interventions to break and create consumer habits. *Journal of public policy & marketing,* **25(1)**: 90-103.
[8] Bhas, N. (2013) Smart wearable devices: Fitness healthcare entertainment and enterprise 2013–2018. *Juniper Res.*, Basingstoke, UK, Tech. Rep.
[9] Feng, S., Mäntymäki, M., Dhir, A., & Salmela, H. (2021) How self-tracking and the quantified self promote health and well-being: systematic review. *Journal of Medical Internet Research*, **23(9),** e25171.
[10] Kang, H. S., & Exworthy, M. (2022) Wearing the Future—Wearables to Empower Users to Take Greater Responsibility for Their Health and Care: Scoping Review. *JMIR mHealth and uHealth*, **10(7)**, e35684.
[11] Leger, D. (1994) The cost of sleep-related accidents: a report for the National Commission on Sleep Disorders Research. *Sleep*, *1***7(1)**: 84-93.
[12] Liang, M., Guo, L., Huo, J., & Zhou, G. (2021) Prevalence of sleep disturbances in Chinese adolescents: A systematic review and meta-analysis. *PLoS One,* **16(3)**: e0247333.
[13] Korotitsch, W. J., & Nelson-Gray, R. O. (1999) An overview of self-monitoring research in assessment and treatment. *Psychological Assessment*, *1***1(4)**: 415.
[14] Scott, H., Lack, L., & Lovato, N. (2020) A systematic review of the accuracy of sleep wearable devices for estimating sleep onset. *Sleep Medicine Reviews*, *4***9**: 101227.
[15] Bianchi, M. T. (2018) Sleep devices: wearables and nearables, informational and interventional, consumer and clinical. *Metabolism*, *8***4**: 99-108.
[16] Bandura, A. (1991) Social cognitive theory of self-regulation. *Organizational behavior and* human decision processes, 50(2): 248-287.
[17] HUAWEI Official Website (2023). HUAWEI WATCH4 series in detail. https://consumer.huawei.com/cn/wearables/watch-4-series/.
[18] Gaiduk, M., Seepold, R., Martínez Madrid, N., & Ortega, J. A. (2023) Assessing the feasibility of replacing subjective questionnaire-based sleep measurement with an objective approach using a Smartwatch. *Sensors*, **23(13),** 6145.