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SLEEP TRACKING AS A STRESSOR: EXPERIENCES FROM SMART RING USERS

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Research Paper

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Abstract

This study explores the stress that users attribute to sleep tracking with a smart ring. Prior research has discussed the challenges and barriers related to sleep-tracking technologies, but specific research on the stress caused by these technologies is scarce. This study explores the potential stressors that users attribute to sleep tracking executed via a smart ring. We conducted 38 semi-structured interviews and used thematic analysis to identify eight potential stressors from sleep tracking: complexity, invasion, inaccuracy, unreliability, data–perception discrepancy, pursuit of perfect data, vague guidance and interpretations, and overload with multiple self-tracking technologies. We further theorize these potential stressors using the person–technology fit model. The paper contributes to the nascent Information Systems research on technostress in the context of sleep tracking.

Keywords: Sleep tracking, Technostress, Stress, Stressor, Person–technology (P–T) fit model, Smart ring.

1 Introduction

Sleep tracking is a subset of self-tracking and is defined as the use of technological tools to monitor, record, and measure one's sleep (Feng, Mäntymäki and Salmela, 2022). Getting enough high-quality sleep allows the body and brain time to rest and recover (Suni and Callender, 2022). A recent survey of 13,000 people from 13 countries revealed that only 55% of adults are satisfied with their sleep (Philips, 2021). Moreover, prior research has found sleep deficiency to be detrimental to physical (Luyster *et al.*, 2012) and mental health (Staner, 2003; Tsuno, Besset and Ritchie, 2005; Grandner, 2017). Sleep is imperative for health (Luyster *et al.*, 2012; Itani *et al.*, 2017; Jike *et al.*, 2018).

The growing public awareness of the importance of sleep for health and well-being has boosted the demand for sleep-tracking technologies and accelerated the user adoption of technological tools for sleep tracking. Echoing these issues, prior research has called for studies on the human–computer interaction aspects of sleep (Choe *et al.*, 2011). Compared to other areas of self-tracking, such as physical activity and diet, sleep is a passive activity (Liu, Ploderer and Hoang, 2015; Ravichandran *et al.*, 2017) that is typically not directly measured but can be inferred from other biological signals (Liang and Ploderer, 2020).

There is a vivid discussion about the barriers and challenges of using sleep-tracking technologies to improve sleep quality (Liu, Ploderer and Hoang, 2015; Liang and Ploderer, 2016, 2020; Shelgikar, Anderson and Stephens, 2016; Ravichandran *et al.*, 2017). According to Liang and Ploderer (2016), sleep-tracking technology can increase awareness of sleep but has less effect on the improvement of sleep quality. While sleep tracking can arguably support behavioral changes toward getting more restorative sleep (Feng, Mäntymäki and Salmela, 2022), the use of sleep-tracking technology can also be a source of stress (Kuosmanen *et al.*, 2022). This is a particularly important issue in the context of sleep tracking because stress negatively impacts sleep (Kim and Dimsdale, 2007) and sleep deprivation can, in turn, increase stress (Staner, 2003; Tsuno, Besset and Ritchie, 2005). However, with a few notable exceptions (Hoogstraten, 2018; Park, 2019; Rieder *et al.*, 2020), there is a paucity of research investigating the stress caused by sleep-tracking technology. Identifying and minimizing the stressors of sleep-tracking technology is important to solve the vicious circle of stress and sleep problems.

Against this backdrop, this paper answers the following research question: *What potential stressors do users attribute to sleep tracking executed through a smart ring?* We use thematic analysis (Braun and Clarke, 2006) to examine the data collected from 38 semi-structured interviews conducted with users of the Oura smart ring. The emerging themes were interpreted through the person–technology (P–T) fit model (Ayyagari, Grover and Purvis, 2011) and corresponded to technology features, P–T misfits or gaps evaluation, and strains. The P–T fit model is a useful tool for elucidating the stressors and understanding their sources from the individual and technological perspectives (Ayyagari, Grover and Purvis, 2011). We identified eight potential stressors: complexity, invasion, inaccuracy, unreliability, data–perception discrepancy, pursuit of perfect data, vague guidance and interpretations, and overload with multiple self-tracking technologies. The results contribute to the nascent research on the dark side of sleep tracking by identifying and elucidating the stressors that users attribute to sleep tracking. In doing so, we advance the understanding of technostress in the self-tracking context.

2 Background

2.1 Sleep-tracking technology

With the development of digital technology and sensors, self-tracking technology has penetrated people's daily lives (Lupton, 2016). With respect to sleep tracking, there are different technologies to monitor and keep track of one's sleep, including mobile apps (Shelgikar, Anderson and Stephens, 2016; Mahmud, Wu and Mubin, 2022) and contact/noncontact devices (Goldstein, 2020). Prior research found that sleep-tracking technologies can help users improve their self-awareness of sleep (Liang and Ploderer, 2016; Ravichandran *et al.*, 2017), facilitate the adoption of healthy sleep habits (Ravichandran *et al.*, 2017), provide decision support for sleep optimization (Kuosmanen *et al.*, 2022), and manage sleep disorders and chronic conditions that affect sleep (Ravichandran *et al.*, 2017).

From the user's perspective, the barriers to improving sleep are a lack of knowledge about normal sleep, diagnosing reasons for a lack of sleep, and finding means how to address the sleep problem (Liang and Ploderer, 2016). While sleep-tracking technologies can help improve sleep, research has also highlighted that poor sleep exists despite sleep-tracking technology use and that the feedback given by sleep-tracking technology has little impact on the improvement of sleep quality (Liang and Ploderer, 2016; Robson, Ellis and Elder, 2022). Moreover, prior research has reported several problems faced by the users of sleep-tracking technologies, such as data interpretation (Liu, Ploderer and Hoang, 2015) and privacy issues (Shelgikar, Anderson and Stephens, 2016). Liang and Ploderer (2020) concluded with two fallacies related to sleep tracking: the sleep fallacy and the black-box fallacy. The sleep fallacy results from the lack of basic knowledge of sleep whereas the black-box fallacy results from the lack of transparency regarding how sleep-tracking technologies work.

Previous research suggests that sleep-tracking technologies can introduce stress to users (Kuosmanen *et al.*, 2022). Furthermore, the constant availability of sleep-tracking data can induce compulsive behaviors and evoke negative emotions, which can, in turn, lead to adverse outcomes (Kuosmanen *et al.*, 2022). Finally, Kuosmanen et al. (2022) reported that balancing the data and the user's perception of sleep was considered a challenge among users of sleep-tracking technologies. Altogether, while previous studies have discussed the challenges and barriers faced by the users of sleep-tracking technologies (Zhang *et al.*, 2019), there is a paucity of research with a deliberate focus on the dark side of this technology (Liang and Ploderer, 2016; Aji *et al.*, 2019).

2.2 Technostress in the personal use of information technology

The term "technostress" was coined by the clinical psychologist Craig Brod. It was originally defined as "a modern disease of adaptation caused by an inability to cope with the new computer technologies in a healthy manner" (Brod, 1984, p. 16). In the Information Systems (IS) field, technostress is the stress experienced by individuals due to the use of information and communication technologies (ICTs) (Ragu-Nathan *et al.*, 2008, p. 418). While technostress has been widely used to explore technological stress in the context of the organization (e.g., Maier *et al.*, 2019; Califf and Sarker, 2020), it has also been applied to the personal use of information technology (IT) (e.g., Weinert, Maier and Laumer, 2015; Benlian, Klumpe and Hinz, 2020; Rieder *et al.*, 2020).

In IS research, social network sites (SNSs) have been a key context for studying technostress (Maier *et al.*, 2015; Salo, Pirkkalainen and Koskelainen, 2019; Tarafdar *et al.*, 2020). The technology characteristics of SNSs, such as push notifications, real-time updates, multipurpose functionality, self-disclosure, and the paucity of information cues (Salo, Pirkkalainen and Koskelainen, 2019), can bring technostress to users when they cannot accommodate user needs or be handled by users (Ayyagari, Grover and Purvis, 2011). This can lead to multiple stressors, such as overdependence on SNSs in behavior and daily activities (Salo, Pirkkalainen and Koskelainen, 2019), social, technological, and information overload (Maier *et al*., 2015; Lee, Son and Kyu, 2016; Brooks, Longstreet and Califf, 2017; Tarafdar *et al.*, 2020), invasion of SNSs in personal life (Maier et al., 2015; Brooks, Longstreet and Califf, 2017), and disclosing too much user's information (Maier *et al.*, 2015; Tarafdar *et al.*, 2020). These stressors can impact SNSs usage, resulting, for example, in addiction (Tarafdar *et al.*, 2020), discontinuance of use (Maier *et al.*, 2015), and exhaustion (Luqman *et al.*, 2017). They can also negatively affect well-being, causing problems related, for example, to concentration, sleep, identity, and social relationships (Salo, Pirkkalainen and Koskelainen, 2019). In addition, prior research found that overload and overdependence on SNSs negatively affect users' ability to fall asleep, as well as sleep quality, timing, and duration (Salo, Pirkkalainen and Koskelainen, 2019).

Different IT characteristics result in different stressors (Ayyagari, Grover and Purvis, 2011). Specifically, wearable-technology users may experience stressors related to technology properties (inaccuracy, unreliability, complexity, and inflexibility), as well as transparency and evaluation (over-transparency, overdependence, and a discrepancy between feeling and data), thereby leading to emotional, cognitive, and behavioral strain (Rieder *et al.*, 2020). However, activity-tracking apps can also help decrease technostress, including overload, invasion, and vigilance regarding technology (Hoogstraten, 2018). Regarding mobile phone usage, compulsive use (Hsiao, Shu and Huang, 2017) and addiction (Lee *et al.*, 2014) are the main stressors that negatively impact an individual's health (Lee *et al.*, 2014). However, Hsiao et al. (2017) found that compulsive smartphone use does not negatively affect academic performance. In the context of smart home assistants, the primary stressor for users is privacy invasion, which can cause interpersonal conflict and strain at home (Benlian, Klumpe and Hinz, 2020).

While prior studies have identified some technostress in the personal use of IT, few have explored technostress in the context of self-tracking technologies, particularly sleep-tracking ones. Identifying and minimizing the stressors in sleep-tracking technologies is important. This calls for researchers to focus on this issue.

2.3 The person–technology fit model

The P–T fit model (Ayyagari, Grover and Purvis, 2011) is derived from the person–environment (P–E) fit theory of stress (Edwards, Caplan and Harrison, 1998). The P–E model is a way to understand the stress caused by the misfit between a person and their environment (Edwards, Caplan and Harrison, 1998; Sudbury-Riley, FitzPatrick and Schulz, 2017). Regarding the technological environment, the P–T fit model can be used to explain how technology characteristics and personal factors influence stressors, which are structured by the "IT characteristics–stressors–strains" (see Figure 1) (Ayyagari, Grover and Purvis, 2011). In the P–T model, technology characteristics, such as system features, are seen as the antecedents of stressors (Ayyagari, Grover and Purvis, 2011). Stressors refer to the factors that create stress. Stressors, in turn, lead to the outcomes of stress for individuals; these are called strains, and they include behavioral, psychological, and physical outcomes (Cooper, Dewe and O'Driscoll, 2001; Ragu-Nathan *et al.*, 2008).

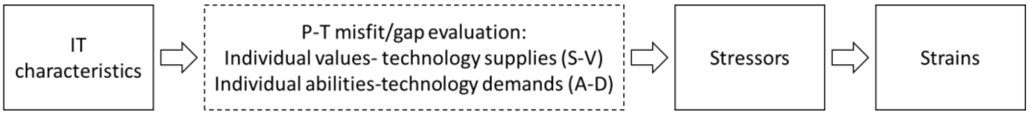

Figure 1. Person–technology fit model (Ayyagari, Grover and Purvis, 2011)

In the P–T fit model, the misfit or gap between a person and technology can induce stress (Ayyagari, Grover and Purvis, 2011). There are two main types of misfits or gaps—namely, the misfits or gaps between technology supplies and individual values (S–V) and those between individual abilities and technology demands (A–D) (Edwards, 1996; Ayyagari, Grover and Purvis, 2011). With respect to the S–V misfit, an individual's values represent their conscious desires, including their interests, motives, and goals (Edwards, 1996; Edwards, Caplan and Harrison, 1998; Ayyagari, Grover and Purvis, 2011). If the technology supplies do not fulfill an individual's values, the discrepancy may lead to stress (Edwards, 1996; Edwards, Caplan and Harrison, 1998; Ayyagari, Grover and Purvis, 2011). The other main type of misfit between the person and technology is the A–D misfit. The A–D misfit refers to a situation in which the person's abilities, including their skills, knowledge, time, and energy, cannot meet the technology demands. The discrepancy manifests in stressors (Edwards, 1996; Edwards, Caplan and Harrison, 1998; Ayyagari, Grover and Purvis, 2011).

The P–T fit model has been broadly used in stress-related research in the IS field (e.g., Ayyagari, Grover and Purvis, 2011; Salo, Pirkkalainen and Koskelainen, 2019; Benlian, Klumpe and Hinz, 2020). The majority of research followed the "IT characteristics–stressors–strains" to build research models and explore the antecedents and consequences of the stressors through quantitative research methods in different contexts, such as ICTs in organizations (Ayyagari, Grover and Purvis, 2011), SNSs (Salo, Pirkkalainen and Koskelainen, 2019), smart home assistants (Benlian, Klumpe and Hinz, 2020), the academic use of mobile devices (Al-fudail and Mellar, 2008; Qi, 2019), and COVID-19 pandemic (Mäntymäki *et al.*, 2022). Other research evaluated the S–V and A–D gaps to explain the stressors in different contexts. For instance, Ayyagari, Grover and Purvis (2011) explained the stressors caused by the misfits or gaps between ICT characteristics and the individual, and Al-fudail and Mellar (2008) explored the misfits or gaps between ICTs in teaching and teachers.

3 Methodology

3.1 Research context

We chose Oura as the research context to investigate the potential stressors induced by sleep-tracking technologies. The Oura smart ring is one of the devices suitable for long-term sleep tracking and can thus help the user better understand their lifestyle and identify potential factors that hinder their sleep quality (Kuosmanen *et al.*, 2022). The Oura ring is an insightful context in which to study sleep-tracking technology use because it combines both daytime and nighttime data to balance activity and sleep. It also provides recommendations to facilitate sleep optimization. The specific focus on sleep and extensive insights and recommendations on how to improve sleep differentiate Oura from, for example, activity-tracking smartwatches, which typically provide a more limited set of sleep parameters without recommendations or insights. Moreover, compared to noncontact sleep-tracking technology, such as smart pads under the mattresses, Oura also tracks daytime data to complement the nighttime data for formulating sleep recommendations.

Oura Health is a health technology company with headquarters and research and development operations in Finland. The smart ring is accompanied by a smartphone application and a cloud platform. The smartphone application synthesizes the sensors' data to provide users with sleep, readiness, and activity scores and recommendations for optimizing sleep, health, and well-being. The third generation of the ring was released at the end of 2021. Thus, both the second and third generations were being used at the time of the empirical research activities. Using the feature information available on the Oura website and reflecting on two authors' firsthand experiences as Oura users, we summarized the features into six main categories: tracking, notifications, guidance and recommendations, scores and rewards, data sharing, and compatibility. The respective information is presented in Table 1.

Feature category	**Description**
Tracking	Sleep: total sleep, time in bed, sleep efficiency, resting heart rate, sleep stage (deep, rapid eye movement, light, and awake), sleep latency, nap detection, and blood oxygen levels*
	Activity: activity detection, steps, heart rate, active calorie burn, recovery time, 24/7 heart rate*, and workout heart rate*
	Readiness: heart rate variability, body temperature, respiratory rate, and restorative time*
	Workout and tag (manually)
	Period prediction*
Notifications	Battery level, inactivity alerts, activity progress, bedtime notifications, and weekly/monthly/seasonal/annual report
Guidance and recommendations	Short verbal recommendations: bedtime and readiness
	Dynamic activity goals (editable)
	Guided audio sessions (meditation, breath, and sleep story)
Scores and rewards	Three scores (sleep, activity, and readiness) and crowns
Data sharing	Oura stickers
Compatibility	Apple Health, Google Fit, Strava, and Natural Cycles
Note: * refers to the new features in generation 3	

Table 1. Oura ring features

3.2 Data collection and analysis

We conducted semi-structured interviews to collect data. We used the snowball sampling approach, starting with the authors' personal and professional networks. We also posted an invitation to the Oura-Suomi (Oura-Finland) Facebook group to recruit additional informants. According to Oura, the ring needs to accumulate data for at least two weeks to provide meaningful insights. Therefore, we focused on experienced and active Oura users. The interviews were conducted in English in April 2021 and September 2022. In total, 38 users were interviewed, of which 14 were male and 24 were female. Two of the interviews were conducted face-to-face, and 36 were conducted online. The interviews lasted from 23 to 58 minutes. Altogether, the interviews generated 1,393 minutes of voice recordings and 138,285 words of interview transcripts. More than half of the informants were between 25 and 44 years old, and 33 out of 38 informants had more than six months of use experience.

The interview protocol comprised four main parts: 1) background questions, 2) use habits (habits related to sleep tracking and the use of different features of the ring), 3) evaluation of the positive and negative sides of the ring (evaluation of the positive and negative aspects of the ring and the positive and negative outcomes of its use), and 4) personal stories, experiences, and critical incidents.

The interview transcript was imported to NVivo 12 software for further organization and analysis. We followed the six stages of the thematic analysis approach (Braun and Clarke, 2006, 2012) to generate themes (potential stressors) from the interview transcripts. The first stage involved familiarizing ourselves with the data. We read the text repeatedly to familiarize ourselves with the interview transcripts. At this stage, we made notes about our observations, our ideas, and the issues to be discussed within the author team. The second stage involved generating initial codes. The first author established 18 initial codes with 139 labeled quotes and presented this list of initial codes to the second author for comments and discussion. The third stage involved searching for themes. We identified several instances of P–T misfits or gaps in the data that could be interpreted as potential stressors. The fourth stage of the analysis involved reviewing the themes. The most relevant codes were extracted and clustered to generate themes related to potential stressors of sleep tracking. As a classic inductive research method, thematic analysis is a recursive process (Braun and Clarke, 2006, 2012). At each stage of thematic analysis, it is necessary to review and check the relevance of the themes, codes, and raw data. The fifth stage of the analysis involved defining and naming the themes. We established eight themes depicting the stressors related to sleep tracking. We theorized these potential stressors using the P–T fit model, and the technology and person misfit or gap corresponding to each potential stressor were identified by revisiting the raw data. In the sixth and final stage, a report was produced to show the coding results (see Figure 2).

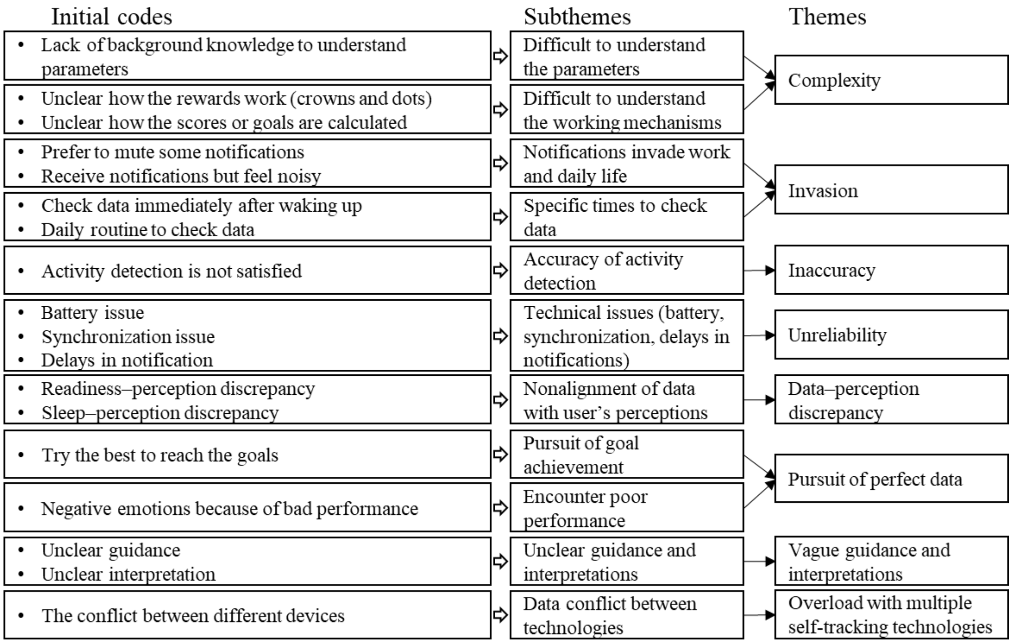

Figure 2. Coding process

We employed five primary means to ensure the trustworthiness of the results and their interpretations (Lincoln and Guba, 1985). First, we followed the same interview protocol with all interviewees. Second, two of the authors are experienced Oura users, which contributed to the preunderstanding of the topic and motivated the interviewees to share and discuss their experiences. Third, the two first authors actively discussed the data and their observations during the data collection and analysis process. Because the third author was not involved in the data collection and first stages of the analysis, he was able to evaluate the analysis and results from an "outsider's" perspective. Fourth, to ensure that the insights derived from the interviews were based on a reasonable amount of experience with the technology in question, we interviewed only experienced Oura users. Fifth, in addition to the interview data, we contextualized the information, as some of the interviewees wanted to further elaborate on their responses by providing screenshots from the Oura app.

4 Potential Stressors of Sleep tracking

Eight themes were generated to describe the phenomena of P–T misfits or gaps that result in negative emotions and compulsive behaviors when using the sleep-tracking smart ring. They can be seen as potential stressors of sleep tracking and are as follows: complexity, invasion, inaccuracy, unreliability, data–perception discrepancy, pursuit of perfect data, vague guidance and interpretations, and overload with multiple self-tracking technologies. Based on the P–T fit model, emerging potential stressors correspond to technology features, P–T misfits or gaps evaluation, and strains. The Appendix details the respective results.

4.1 Complexity

Complexity describes the situation in which users perceived sleep-tracking technology as technically difficult to use (adapted from Tarafdar *et al.*, 2020). In the context of sleep-tracking smart rings, some users may experience technical complications due to an insufficient understanding of parameters and work mechanisms.

We observed that most of the interviewed Oura ring users could understand the meanings of the parameters because they were able to find explanations in smartphone applications or search websites for biophysiological knowledge. However, some users may encounter problems in understanding the meanings of the parameters provided by the device. The informants who articulated that they had this problem were novices and the elderly. This may imply that learning the functions of the device and how to interpret the data it provides takes time. Moreover, the presentation of certain technical information may be challenging for some user groups. All in all, this hints at a potential misfit between users' abilities and the demands of sleep-tracking technologies. The following interview quote elaborates on this:

> "*This one that I don't understand. It's the restorative time. I think I can see that. Okay, now it's going up…bigger measurements. So, I think it's good, but I really don't understand what it is.*" (I18)

Most informants elaborated on the Oura ring's complexity that is attributed to its nontransparent scoring and reward mechanisms. For example, some informants stated that they did not know which behavioral changes could help them improve their activity scores. Furthermore, Oura's reward mechanism raised critical voices among the informants, as there was no clear way to earn crowns and dots. This means that to receive positive feedback from the ring, the user needs to be active in determining how the scoring and reward mechanisms work. The following quotes elaborate on the respective misfit between the users' needs and the sleep-tracking technology:

> "*The activity score is not something I follow so much because the activity score is a little bit difficult. I really don't know how it works. Sometimes, it gives good scores when you're active. Sometimes, it gives good scores when you're not active. So, I don't really know what it is and its parameters. It is difficult to know what to do to get good scores.*" (I36)
>
> "*For example, one thing that I don't really understand is the month screen where the dots are. I never know when the dots will come and when they won't come. I've spent a few minutes trying to figure that out, but I really don't know.*" (I07)

4.2 Invasion

Invasion describes the situation in which sleep-tracking technology invades users' daily lives with negative perceptions or becomes an integral part of everyday life (adapted from Maier *et al.*, 2012, 2015). In the context of sleep-tracking technology, two aspects were shown: intrusion notifications and specific times to check data.

Invasion was mentioned in conjunction with the notification features. Oura provides user notifications about battery levels, periods of physical inactivity, progress in reaching the daily activity goal, the bedtime window, and the report on a weekly, monthly, quarterly, and annual basis. It frequently reminds users of some cues or recommendations that need to be highlighted. For example, users can receive hourly notifications while they are inactive. Some users dislike notifications. More than a quarter of the informants stated explicitly that they considered the notifications annoying, particularly because they perceived them as conflicting with their subjective experiences. Hence, being unable to comply with the recommendations given by a self-tracking device can evoke feelings of stress and guilt. Echoing this issue, seven of the 38 informants reported that they had turned off the notifications to reduce the potential stress arising from being unable to act upon the recommendations.

> "*Most of the notifications, in my opinion, are very annoying. And the Oura notifications are one of the least annoying, but still annoying. I don't like notifications in almost anything else... All the other notifications that pop up usually break my concentration. That's not good.*" (I12)
>
> "*There are so many notifications in my life. I don't want any more. I would think they would be stressful because I cannot do anything about this notification. If it tells me to stand, jump, run, or eat, it doesn't make any sense, because I cannot comply.*" (I17)

The invasion of sleep-tracking technology is also visible in how users check their data and sync the device. Users may have a specific time to check and synchronize the data. Because Oura is a sleep-tracking ring without a screen, users need to synchronize the data from the Oura ring to the smartphone application to check the data. The ring recommends that users synchronize the data daily because of its limited storage capacity. Furthermore, users are interested in the sleep data when they wake up. There is a fit between user needs and sleep-tracking technology supplies. However, approximately one-third of the informants stated that the first thing they did in the morning was open the application to see how well they had slept. Users have an addiction-like checking behavior with regard to obtaining timely sleep data and keeping these data constantly available. It is not beneficial to overemphasize the data and ignore real feelings. Therefore, the intrusion of sleep-tracking technology could lead to compulsive behavior.

> "*When I wake up, it's one of the first things I do… But in the morning is one typical time. So it also helps me wake up. Because if I don't do anything, I don't wake up. So the first thing I do is check Oura and see, like, the readiness score and the sleep score.*" (I24)
>
> "*Of course in the morning. I mean, that's a bad habit. But I open it. It is the first thing in the morning to go to see how well I slept.*" (I26)

4.3 Inaccuracy

Inaccuracy refers to a situation in which the sleep-tracking technology does not track the data accurately (adapted from Rieder *et al.*, 2020). Some informants opined that Oura's activity detection was not as accurate as expected. Improving detection accuracy is a goal that every self-tracking technology is pursuing. As a sleep-tracking smart ring, Oura emphasizes the balance between sleep and activity and pays much attention to sleep and recovery. Activity tracking is not Oura's strong point when compared with professional activity-tracking technologies. Some activities cannot be automatically detected accurately. A missing workout cannot be included in the scoring mechanisms for calculation, which affects the score. This is problematic, as users think that the activity detection is inaccurate, and the S–V misfit makes them feel disappointed and unhappy.

> "*Yes, it does [automatically track activities] if you are doing some heavy activities, but for yoga, for example, it doesn't register. So it depends on the activity*." (I36)
>
> "*I have noticed that Oura is very poor at picking up real exercises. It never recognizes when I go bowling. It never understands that this man has been bowling… Oura thinks this is not exercise. It always says to stretch your legs. That's my biggest disappointment with Oura.*" (I33)

4.4 Unreliability

Unreliability describes situations in which users cannot engage in sleep-related behavioral intervention due to the problem with sleep-tracking technology (adapted from Califf and Sarker, 2020; Rieder *et al.*, 2020). The most frequently mentioned issue related to unreliability was battery life, followed by minor issues with synchronization and delay notifications. The S–V misfit may cause users to experience emotional strain.

A quarter of the informants experienced battery issues, and most of them are users of the second-generation Oura ring. Some had to contact customer service to replace a new device. Because of the battery issue, users need to charge their Oura ring frequently, which is not what they expected. For the new generation oura ring users, one informant mentioned that new features, such as blood oxygen sensing, cause high battery consumption, leading him to turn off new features to save power. Moreover, users may lose data if the battery runs out at night. Therefore, the unstable battery issues made informants feel disappointed and frustrated.

> "*It's actually my third ring... Before that, I had two Oura rings because of the battery life. It was so bad. The first one went down very fast. So that was disappointing…very disappointing.*" (I03)
>
> "*Once the battery ran out at night, [and] I didn't get my sleep score. I had done everything perfectly the evening before, and I was thinking, okay, it would be the best sleep score ever. But I didn't get a sleep score that day, which was frustrating.*" (I12)

Some minor issues were also mentioned during the interviews, such as synchronization and delayed notifications. Some informants stated that it took a long time to synchronize the data, which requires a great deal of time and focus on the synchronization process. Furthermore, late notifications confuse users, which could also be an issue in Android ecosystems.

> "*Sometimes, it takes too long to kind of sync from ring to app. So sometimes, it is quite cumbersome. That is making me upset, but nothing else.*" (I34)
>
> "*They [notifications] are not very good, though. They come very late. I would sit on the sofa and watch a movie for two hours, and all of a sudden, it says, 'Congratulations. Your activity goal has been achieved.' And I am like, what? I've been sitting here for two hours, and then I check that it was actually already many hours before.*" (I23)

4.5 Data–perception discrepancy

The discrepancy between data and perceptions describes situations in which users experience a disconnection between their subjective perceptions about their performance and the data that they usually trust (Rieder *et al.*, 2020). While using the Oura ring, some informants stated that the sleep-tracking technologies' data could not explain their perceptions. There is an S–V misfit between users and sleep-tracking technologies. In other words, sleep-tracking technologies cannot provide matching data to help confirm users' states. Because of the discrepancy between perceptions and data, users may have negative emotions about the technologies, such as disappointment and doubt.

> "*Last night is a perfect example. It is really bad… Oura recorded that I stayed awake. But it still gave me a really good readiness score. The analysis isn't very convincing. So I sort of have to admit I'm slightly disappointed in some things with Oura. For instance, my subjective feelings for certain things are very different.*" (I37)
>
> "*I know if I have slept badly, then okay, I know it. But sometimes, the score doesn't make sense [based on] how I feel, and then I just say, 'Oh my god. That's not right.'*" (I26)

4.6 Pursuit of perfect data

The pursuit of perfect data describes the situation in which the sleep-tracking technology provides scores and goals for users, who may feel stressed when they actively strive to obtain higher scores. (adapted from Kuosmanen *et al.*, 2022). This potential stressor may lead to engagement in obsessive behaviors to achieve goals and negative emotions when encountering bad performance.

Oura provides three scores: sleep, activity, and readiness. When a user achieves 85% of the scores, they receive a crown. Moreover, Oura provides daily dynamic activity goals to prompt users toward an appropriate activity level to optimize their sleep. Some informants indicated that they take the data seriously and follow the recommendations and goals closely. Some informants, in turn, expressed that they might practice more if they had a small gap between the actual performance and the target goal. People who want perfect data find that sleep-tracking technology provides goals and rewards that can meet their needs. However, this may also result in compulsive behaviors, such as focusing solely on the numeric feedback and doing extra workouts solely to achieve goals.

> "*I also think for the activity. You can see the numerical data. For example, if my daily activities are like 550 and then I notice, okay, I'm here at 490, so I will take extra steps to reach it.*" (I15)
>
> "*At times, I've really tried to get to the activity level target of 100, which I've managed to do maybe five times in half a year. But that is really difficult.*" (I31)

Some informants reported experiencing negative feelings when faced with low performance scores. Users may feel frustrated, anxious, sad, and bad when they see that their actual performance is lower than the average level or when they get bad scores. There is a misfit between users' capabilities and the demands of the sleep-tracking technologies; this can, in turn, demotivate users and even affect their mental health and sleep.

> "*There are people who want to be perfect. They want 100% and 100 points every day. If they cannot achieve that, they become anxious. But they won't even sleep well anymore.*" (I19)

> "*When I did not sleep so well, my readiness score was not so good as well. Then it was lower. And then I had a negative feeling. Not because the activity goal was lower, but I did a bad job of sleeping.*" (I24)

4.7 Vague guidance and interpretations

Vague guidance and interpretations describe a situation in which sleep-tracking technology cannot help users find exact reasons for their poor performance and how to improve it in line with the real situation. The Oura ring automatically interprets sleep results and provides coaching, which is better than many self-tracking devices that provide parameters only. However, six informants still complained that they did not know how to improve their scores. They tried every recommendation provided by Oura to improve their scores. For example, one informant stated that he had a stable sleep rhythm with no alcohol, no late eating, and exercise, but these did not lead to desired effects on the sleep score. Another informant had the same problems. He always received the same default text if some parameters were not good enough. It is hard for users to find real reasons and effective ways to improve it. The misfit between users' needs for clear guidance and interpretations and sleep-tracking technology supplies may negatively affect users' emotions and decrease their motivation to continue using the device.

> "*One frustration is that when I get the average point below the average readiness or sleep score, and even though the Oura [ring] gives guidance on how you should improve, at least for me, there is no effect.*" (I13)
>
> "*I'm a little bit annoyed when I click on the detailed information. It always tells you the same things about those metrics. So if your heart rate variability is low, it always gives you the same default text.*" (I16)

4.8 Overload with multiple self-tracking technologies

Overloading with multiple self-tracking technologies describes the situation in which users receive too much information because they have more than one self-tracking technology (adapted from Maier *et al.*, 2015). Because Oura highlights the balance between sleep, activity, and recovery, users who demand professional activity tracking and coaching prefer to use another activity-tracking technology to complement Oura. This misfit between sleep-tracking technology supplies and users' needs for activity may lead to the use of multiple self-tracking technologies simultaneously.

Surprisingly, more than half of the informants in our research used Oura with other self-tracking technologies—for example, smartwatches such as Polar, Garmin, and Apple, as well as self-tracking applications, such as Strava. The use of multiple self-tracking technologies inevitably results in information overload. Several informants stated that they encountered data conflict between multiple self-tracking technologies, such as the gap between the step counts, activity goals, and sleep cycle. In addition, the various devices may offer different suggestions. For example, Oura may suggest resting, while other devices may prompt users to do more activities. Users do not know what to believe (A–D misfit), and too much conflicting information makes them feel confused.

> "*I had a lot of data for that [step counts]. So, for example, it was 17,000 in Oura, and it was 26,000 in Polar. Or it was 15,000 in Oura, and it was 19,000 in Polar. That was a big, big difference. That's really confusing*." (I11)
>
> "*For me, this has become a complicated thing because now that I'm using two sleep-tracking devices, sometimes the results I get are mixed. Then I don't know what to believe.*" (I09)

5 Discussion

5.1 Key findings

This study explores the stressors of sleep tracking. Based on the interview data, we generated eight potential stressors emerging from the P–T misfits or gaps phenomena that adversely affect users of a sleep-tracking smart ring. Some interesting results regarding the potential stressors of sleep tracking are found in this research.

First, eight potential stressors in the context of sleep-tracking technologies were generated. In prior research, the stressors of invasion, inaccuracy, unreliability, complexity, and data–perception discrepancy were discussed in the context of wearable devices (Hoogstraten, 2018; Rieder *et al.*, 2020). However, some new potential stressors are interesting when discussed in the context of sleep tracking; they include vague guidance and interpretations, the pursuit of perfect data, and overload with multiple self-tracking technologies. These sleep-tracking potential stressors also coincide with critical archetype users' negative experiences, such as overemphasizing the data and compulsive behavior vis-à-vis checking the data (Kuosmanen *et al.*, 2022).

Second, according to the P–T misfits or gaps evaluation, the misfits or gaps of the S–V dimension are a major potential stressor in the context of sleep tracking. It means a gap exists between sleep-tracking technology supplies and users' values, preferences, needs, or expectations (Ayyagari, Grover and Purvis, 2011). Specifically, the work mechanisms of sleep-tracking technology are not transparent; feedback needs to be contextualized and personalized; and activity-tracking features need to be improved with regard to the balance between sleep and activity. These results are also in line with the previous sleep tracking research that highlighted the importance of personalized feedback (Liang and Ploderer, 2016; Ravichandran *et al.*, 2017; Nguyen *et al.*, 2018) and algorithm transparency (Ravichandran *et al.,* 2017) in the design and improvement of sleep-tracking technology. In addition, the misfits or gaps of the A–D dimension in the evaluation are not the main potential stressors for users of sleep-tracking technology. This means that users have the ability to handle sleep-tracking technology to some extent. However, our results suggest that users who are keen on obtaining good results may develop compulsive tendencies toward sleep-tracking technology.

Third, the main strains in the context of sleep-tracking technology are emotional. We found that most potential stressors of sleep tracking lead to emotional strains, such as frustration, confusion, and disappointment. A few potential stressors result in behavioral strains, such as checking data immediately after waking up, focusing solely on numeric feedback, and doing extra workouts solely to achieve goals. Even though some adverse emotions exist in their user experiences, the users in this research were somewhat satisfied with this sleep-tracking smart ring. In prior research, Hoogstraten (2018) found that technostress did not influence users' performance or enjoyment in the context of activity tracking. It is difficult to conclude that these potential stressors or strains negatively affect adoption or post-adoption behaviors.

5.2 Implications

This study has three main research implications and two practical implications. First, we identified eight potential stressors related to sleep tracking. Stressors of vague guidance and interpretations, the pursuit of perfect data, and overload with multiple self-tracking technologies are new stressors in the sleep-tracking context compared to prior self-tracking research (Hoogstraten, 2018; Rieder *et al.*, 2020). The results contribute to the research on technostress attributed to sleep tracking. As one of the three pillars of a healthy lifestyle (Choe *et al.*, 2011), the results can also extend to general self-tracking devices (Hoogstraten, 2018; Park, 2019; Rieder *et al.*, 2020) because the relationship between sleep and other bio-signals is entangled and intertwined.

Second, considering the growing attention to the dark side of self-tracking technology (e.g., Attig and Franke, 2019; Lupton, 2019; Rieder *et al.*, 2020), limited attention has been paid to the dark side of sleep-tracking technologies (Liang and Ploderer, 2016; Kuosmanen *et al.*, 2022). The results of this research are consistent with the dark side of self-tracking technology on individual emotions (Rockmann, Salou and Gewald, 2018; Toner, 2018) and behaviors (Baumgart and Wiewiorra, 2016; Attig and Franke, 2019). This study highlighted the emotional strain, a major strain in sleep tracking, and contributes to the IS research on the dark side of sleep-tracking technologies.

Third, in this study, we used the P–T fit model to interpret the potential stressors in the context of sleep tracking. In prior research, the P–T fit model has been used in the contexts of an organization (e.g., Ayyagari, Grover and Purvis, 2011), IT for personal use (e.g., Salo, Pirkkalainen and Koskelainen, 2019), and IT-mediated coping with non-IT-related stressors (e.g., Mäntymäki *et al.*, 2022). This study expands the application domain to the sleep-tracking context.

Concerning practical implications, we found that potential stressors mainly resulted from the misfit between the supplies of sleep-tracking technology and user values, such as false activity detection, unclear working mechanisms, and vague guidance and interpretations. The designers of sleep-tracking technology should be cognizant of these potential challenges. For example, the modular design could be applied to the functional design, which could be customizable to meet different users' needs (Liang and Ploderer, 2016; Jarusriboonchai and Häkkilä, 2019); feedback could be personalized by considering lifestyle data and personality characteristics (Liang and Ploderer, 2016; Ravichandran *et al.*, 2017; Nguyen *et al.*, 2018); and the transparency of the working mechanism could be maximized while maintaining the technology's exclusivity (Liu, Ploderer and Hoang, 2015; Ravichandran *et al.*, 2017; Liang and Ploderer, 2020).

Second, users need to pay more attention to their perceptions. Our results suggest that some potential stressors are driven by the discrepancy between users' expectations and the scores given by the device. Furthermore, our results imply that an overemphasis on the results provided by the device can induce stress. In particular, overreliance on sleep-tracking technology can potentially alienate users from trusting their perceptions regarding the amount and quality of sleep. Altogether, sleep-tracking technology is still at the level of tools that can potentially support users' extrinsic motivation (Ryan and Deci, 2000) to improve their sleep habits. However, based on our results, it seems that reinforcing and maintaining intrinsic motivation for healthy sleep habits with sleep-tracking technology remains a challenge. Users need to trust their own instincts and feelings and to listen to themselves.

5.3 Limitations and future research

This study has some limitations that need to be acknowledged. First, our informants were highly educated and presumably more interested in and skilled at using digital technologies in their private and professional lives than the general population. Moreover, it is plausible to assume that persons who purchase a dedicated sleep-tracking device differ from the general population in regard to their disposable income and attention to health and well-being. Second, we used only one method, semi-structured interviews, to collect the empirical data. Future researchers could consider mixed-method research designs (Mäntymäki and Riemer, 2016) to investigate stressors in the context of sleep tracking. Third, this study focused on and theorized potential stressors of sleep tracking based solely on the P–T fit model. Further research could use quantitative methods to analyze the connection between the eight potential stressors, user stress, and stress outcomes (Salo, Pirkkalainen and Koskelainen, 2019). Furthermore, to minimize the harms of the potential stressors, it is important to understand how people cope with IT-induced stress (D'Arcy, Herath and Shoss, 2014; Salo, Makkonen and Hekkala, 2020) and how IT can be used to cope with non-IT-related stress (Mäntymäki *et al.*, 2022). Both of these aspects of coping warrant future research in the context of sleep tracking.

6 Conclusion

It is important to identify the stressors of sleep-tracking technology because of the vicious circle between sleep and stress. In this paper, we applied the person-technology (P–T) fit model to interpret potential stressors of sleep tracking from evaluation misfits or gaps between individual values and technology supplies, and individual abilities and technology demands. Through a thematic analysis, eight potential stressors attributed to the sleep-tracking smart ring were identified and corresponded to technology features, P–T misfits or gaps evaluation, and strains. These potential stressors are complexity, invasion, inaccuracy, unreliability, data–perception discrepancy, pursuit of perfect data, vague guidance and interpretations, and overload with multiple self-tracking technologies. Our findings contribute to the nascent research on technostress related to self-tracking in general and sleep tracking in particular.

Appendix: Interpretation of potential stressors of sleep tracking using P–T fit model

Potential stressor	**Subcategory potential stressor**	**Technology feature**	**P–T gap**		**Effect**	**Dimension**	**Strain**
			Person	**Technology**			
Complexity	Difficult to understand the parameters	Tracking	Lack of background knowledge Lack of time to explore	Health-related knowledge needed	Misfit	A–D	Emotional: confusion
	Difficult to understand the working mechanisms	Scores and rewards	Need to explore the inner workings Expectations of higher scores	Working mechanisms not transparent	Misfit	S–V	Emotional: confusion
Invasion	Notifications invade work and daily life	Notifications	Preference for no notifications	Too-frequent notifications Notifications that do not match real scenes	Misfit	S–V	Emotional: annoyance, stress, guilt, frustration
	Specific times to check data	Tracking Guidance and recommendations Scores and rewards	Need for timely and complete information Need for information about trends	Information provided on demand	Fit	S–V	Behavioral: compulsive behaviors (check data immediately after waking up)
Inaccuracy	Accuracy of activity detection	Tracking	Need for accurate activity tracking	Inaccurate activity detection	Misfit	S–V	Emotional: unhappiness, disappointment
Unreliability	Technical issues (battery, synchronization, and delays in notifications)	-	Need for reliable operation	Problems that affect usage	Misfit	S–V	Emotional: frustration, upset, annoyance, sadness, disappointment
Data–perception discrepancy	Nonalignment of data with user's perceptions	Tracking Scores and rewards	Need to make sense of feelings	Tracking does not coincide with user's perceptions	Misfit	S–V	Emotional: disappointment, doubt, confusion
Pursuit of perfect data	Pursuit of goal achievement	Tracking Guidance and recommendations Scores and rewards	Expectations of higher scores	Supplies goals and rewards	Fit	S–V	Behavioral: compulsive behaviors (focusing solely on numeric feedback and doing extra workouts solely to achieve goals)
	Encounter poor performance		Inability to obtain good results	Quantified low performance	Misfit	A–D	Emotional: frustration, feeling bad, sadness, depression, anxiety
Vague guidance and interpretations	Unclear guidance and interpretations	Guidance and recommendations	Need for exact guidance and interpretations	Unclear guidance and interpretations	Misfit	S–V	Emotional: frustration, annoyance
Overload with multiple self-tracking technologies	Data conflict between technologies (if using two or more devices at the same time)	Tracking Guidance and recommendations Scores and rewards	Need for professional activity tracking Inability to know what to believe	No professional activity tracking Information overload Conflict between technologies	Misfit Misfit	S–V A–D	Emotional: confusion

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