Sleep Tracking: The False Dichotomy between Manual Methods and Automation with Wearables

Hannah R. Nolasco[1,a)] Andrew Vargo[2,b)] Ko Watanabe[3,c)] Koichi Kise[2,d)]

Abstract: Self-tracking is able to encourage positive behavioral changes in individuals who monitor 24-hour behaviors such as physical activity, sedentary behavior, and sleep. Sleep in particular can be improved through manual self-tracking using digital interventions that are equipped with Behavior Change Techniques (BCTs). Wearable devices automate both the process of collecting personal data and the act of aggregating insight from the information, but this leaves users feeling disengaged from their devices. We explored the lived experiences of 8 long-term users of the Oura Ring, a sleep monitoring device, to examine the potential reasons behind the inability of sleep wearables to affect change in spite of the accuracy of its captured objective data. We compare the features and differences between manual and automated self-tracking and propose potential solutions for improving the impact of the latter modality.

1. Introduction

Despite the accuracy of wearable devices in capturing physiological data, users exhibit an absence of incentive to modify their behavior for the benefit of their sleep health [1]. For example, even after a year of usage, users of the Oura Ring, a sleep monitoring device, report subjective perceptions of sleep improvement while their objective data presents either a stagnant or downward trend in sleep quality over time [2]. To the best of our knowledge, there is no salient explanation for this phenomenon and no existing literature that explores this issue.

In this paper, we examine the lived experiences of both past and present users of the Oura Ring to better understand the hurdles faced by sleep tracking through wearables. We collected insights on the struggles that users faced using semi-structured interviews that covered their overall experience with the ring, their relationship with their sleep, and the knowledge they had of the contributors to sleep that were tracked by the device. With the support of existing literature, we discuss the prevailing strengths of self-tracking and propose potential interventions that can be taken to make wearables more relevant to a wider range of people.

1.1 The Oura Ring

The Oura Ring is a commercially available consumer-oriented wearable device designed for sleep monitoring. It is fitted with research grade sensors that measure several physiological markers throughout the day and night, which includes physical activity (Figure 2), heart rate, and heart rate variability (HRV) [3] (Figure 3). All captured data is communicated daily on its accompanying mobile application, where it also displays a calculated **Sleep Score** that summarizes the overall quality of the user's sleep in the previous evening based on seven key contributors: their **Total Sleep** in hours and minutes; their **Sleep Efficiency** in hours and minutes, which represents the time they spent asleep while they were in bed; their **Restfulness**, or whether their sleep remained uninterrupted by any movement or wake-ups; their

Fig. 1 Sleep Contributors on the Oura Application

[1] Osaka Prefecture University
[2] Osaka Metropolitan University
[3] DFKI
[a)] df104001@st.osakafu-u.ac.jp
[b)] awv@omu.ac.jp
[c)] ko.watanabe@dfki.de
[d)] kise@omu.ac.jp

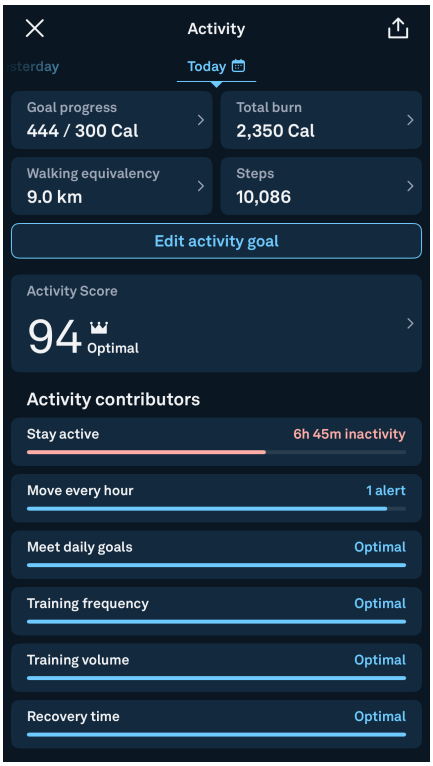

Fig. 2 Activity Tracked by the Oura Ring

Fig. 3 Heart Rate and HRV Tracked by the Oura Ring

Rapid Eye Movement (REM) and **Deep Sleep** durations represented in hours and minutes and by their percentage relative to their total sleep; their **Sleep Latency**, or the time it took to fall asleep, and the **Timing** of when they went to sleep and woke up the next day (Figure 1).

Constant long-term usage of the Oura Ring is crucial to drawing up a blueprint of the wearer's normal vitals and what daytime and nighttime habits will best optimize their sleep quality, which the device recommends once it builds a history of the user's lifestyle and behaviors (`https://ouraring.com/blog/readiness-score/`). The ring has been proven to be accurate in its detection of sleep stages and in its prediction of sleep quality [4]. It is comparable in accuracy to medical sensors such as electrocardiography for heart rate monitoring [4] and research actigraphy and polysomnography for sleep tracking [5].

2. Self-Tracking

Self-tracking is the core element of the Quantified Self (QS) movement [6], in which habits are optimized through the routine monitoring of daily health-driven behaviors, such as physical exercise [7], nutrition and sedentary behavior [8], and sleep [9]. Wearable devices provide individuals with the opportunity to track even more granular information of their activities and physiological markers through the use of data derived from sensors. Not only do these devices reduce the capture burden of long term manual self-tracking, they allow for the collection of more accurate objective data on health parameters [10], [11] and even assist in supporting medical diagnosis of disease [12].

Manual self-tracking methods performed digitally using a smartphone application have proven to be effective in transforming habits in users based on their subjective reporting. Persuasive applications geared towards improving sleep quality using Behavior Change Techniques (BCTs) are successful in affecting significant positive change in users over a short period of use [13], as is manual self-tracking where self-reflection of sleep hygiene practices is encouraged [14]. Out of the many BCTs, users who track 24-hour movement behaviors (i.e., sleep, physical activity, and sedentary behavior) derive the most benefit from receiving knowledge on how to best lead a healthy lifestyle, learning more about the outcomes of health-related behavior, self-monitoring, and receiving feedback, instructions, or tips [15]. In addition to this, instilling and routinely reinforcing knowledge of sleep hygiene in conjunction with manually self-tracking of any relevant daytime and nighttime behaviors using a mobile app intervention has been found to have a significant positive relationship with sleep quality [16]. Adopting sleep hygiene practices is known to improve sleep health [17], yet information on good sleep-related habits is not communicated in conjunction with objective sleep data in the Oura application and is confined to its own section.

In spite of the proven advantages of using BCTs and encouraging self-reflection in users of self-tracking interventions, wearable devices do not offer any features that collect subjective data and instead automates the gathering of insight, risking a loss of awareness, self-reflection, and engagement in its users [14].

3. User Experience with the Oura Ring

In a laboratory-wide project covering the Oura Ring, more than 100 graduate and undergraduate university students have volunteered to wear the device in-the-wild for an unrestricted duration of time with no limitations on their usage and with no penalties for intermittent use or the cessation of use. 8 members of this cohort were interviewed regarding their experiences with the ring. Each participant contributed an average of 16 months or 1.5 years

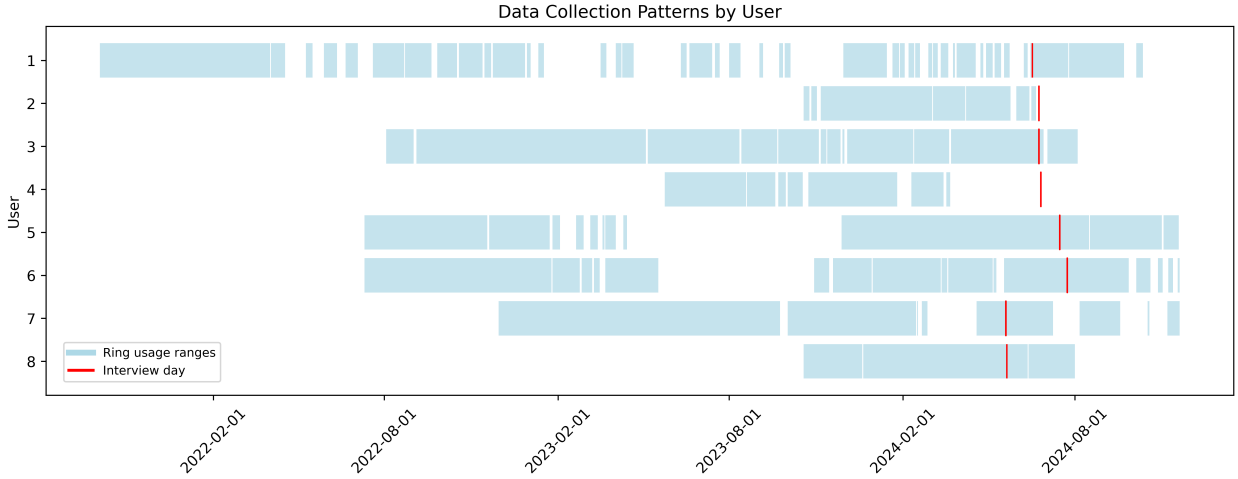

Fig. 4 Usage Pattern of the 8 Respondents

of data, or between 230 and 712 days of total non-continuous usage before they were interviewed (Figure 4). In this section, we outline the interview procedure and elaborate on the key insights lifted from their responses.

3.1 Interview Process

A semi-structured interview framework was designed around three key points of interest: **(1)** the user's usage habits with the ring and their assessment of its comfort, aesthetics, and sensor fidelity; **(2)** their adherence to sleep hygiene practices and their relationship with sleep, particularly its placement among their priorities; **(3)** and their knowledge of the sleep contributors measured by the device. Two pilot interviews were conducted to evaluate the framework's efficacy in collecting sufficient information, after which it was expanded and refined further. Two researchers served as interviewers, one for participants who preferred to communicate in English and another for participants who were more comfortable with Japanese. 5 interviews were held in Japanese and 3 were held in English. Each interview lasted between 1 to 1.6 hours. The interviewers sometimes asked additional questions based on the responses provided.

All interviews were transcribed into text using a speech to text application and were then manually checked by the interviewers for accuracy. Interviews in Japanese were machine translated before being vetted by the Japanese-speaking interviewer.

The experiment was approved in advance by the ethics committee at the Graduate School of Informatics at Osaka Metropolitan University. All participants received informed consent.

3.2 Lack of Information Gain

Users report a disconnect from their captured data due to the attitude that the information can already be discerned by themselves. According to one respondent, they do not think there was any "practical usability gain" from the Oura Ring's calculations: if they feel as though they slept poorly or did not rest well, they already know this without the ring telling them so.

Certain information is seen as exceptionally novel, particularly the effects of alcohol intake on sleep quality. Several respondents volunteered it as a very interesting detail, although it only invokes inquisitiveness upon the initial discovery. Some users were impressed by the device's heart rate capture during cardiovascular exercise and the changes in their data over the course of their menstrual cycle, but many reported sensing a slight incongruence between Oura's scores and their self-perception of how well they slept. This gulf between the subjective feeling of users and their objective data aligns with related literature, which cites a growing body of research highlighting a deficient correlation between subjective and objective measures of sleep characteristics. [18].

3.3 Learned Helplessness

When probed about their adherence to sleep hygiene practices, respondents communicated a sense of powerlessness when it came to affecting their sleep data through better habits. They expressed a lack of knowledge of how Oura's sleep contributors can be influenced in spite of this information being available on the mobile application, or pointed to circumstances beyond their control (e.g., work, school, social life, new environment) as reasons that they could not commit to changing their behavior. Having a lack of structure in their life, such as a job which requires them to abide by a certain number of work hours, is another obstacle in forming self-discipline.

3.4 Selective Interest

The seven key sleep contributors that the Oura Ring tracks is summarized in one dashboard on the mobile application, allowing users to view the characteristics of their sleep at a glance. However, when asked to define each sleep contributor or to provide their optimal measurement, most respondents could not provide sufficient answers or even expressed not knowing what some of these contributors were. A user could assert having a dedication or interest to sleep tracking and improving their sleep quality but will only report paying attention to deep sleep and no other measure. One respondent said they did not know that the other contributors were important despite them all having the same information hierarchy.

4. Discussion and Conclusion

Manual self-tracking through digital applications has the potential to augment human behavior and enhance the quality of life in individuals. It has been confirmed to impact sleep-related habits in positive and meaningful ways [13], [14], [15], [16], yet a wearable device designed for sleep monitoring which automates the collection of measures with incredible accuracy does not seem to encourage the same effect [1], [2]. Adjacent literature has revealed a cross-cultural wellbeing improvement in users of wearables who successfully integrate its use into their lives [19], which provokes us to speculate on the potential reasons why the Oura Ring cannot seem to achieve this.

Given that an increase in outcome expectations during manual self-tracking has an inverse interaction with sleep quality [16], it is possible that the high sensor fidelity and perceived sophistication that users have of the Oura Ring contributes to the lack of improvement in their sleep. Due to having astronomical expectations that the device will solve their issues on their behalf, users are poised to inaction and wait for instructions that never arrive. This may be the reason that they fail to see any benefit from the information the ring provides as it does not come accompanied with actionable guidance that lends it practicality. It is also possible that the nature of sleep itself is too idiosyncratic a behavior to track through a wearable. There is even an argument that quantifying sleep diminishes the act into an achievement rather than a highly subjective experience that looks different for everybody, which feeds into a burgeoning social anxiety to attain perfect sleep [20]. Studies do show that sleep tracking can induce preoccupied perfectionism in users to the point of catastrophic thinking if their tracker data is not up to standard, even going as far as to hurt their ability to work with a healthcare provider [21].

The pitfall of automated data collection irrespective of its better accuracy and greater information granularity is that it alienates people from their data, which they appear to make much better sense of when they collect it themselves [22]. It is becoming increasingly apparent that a hybrid approach to data collection in self-tracking that combines both subjective and objective measures is best for capturing a comprehensive picture of a person's sleep [18], [22]. This conforms with existing literature on what users desire from their wearables: they would prefer to have a tailor-made experience built from the foundations of their personal history [23], which would require some manual documentation of what makes their needs and preferences unique. Manufacturers may also endeavor to extrapolate several different user personas of varying and distinct circumstances that merit discrete styles of device usage to better tailor to different types of people [24]. This may help with finding and targeting the myriad obstacles that users might find too challenging to change about their behavior or their environment; some of these may simply have to be accepted as factors to work around or can be confronted through tailor-made feedback. It is crucial that the user builds confidence in their ability to transform their lifestyle, as self-trackers derive more sleep quality as their perceived capability increases [16].

Although continuous and long-term self-tracking is posited to be the optimal means of leveraging the benefits of wearables, evidence has shown that the impact of self-tracking on behavior remains even after discontinuance [25]. This supports adjacent literature suggesting that short-term device usage is a feasible option that increases its usefulness to the user [23]. Allowing users of wearables to define the duration of their device adherence and to what extent they engage their data may alleviate the pressure to achieve 'perfect' sleep; instead, it may encourage them to approach a sleep pattern that satisfies their personal contexts. In addition to this, providing actionable feedback in an accessible language can nudge users to look at the comprehensive picture of their raw data instead of by piecemeal and feel more empowered to cascade the information into action [23].

4.1 Conclusion

In this paper, we discussed the phenomenon of manual self-tracking and its ability to affect behavioral change in individuals who monitor 24-hour behaviors (i.e., physical activity, sedentary behavior, and sleep). Sleep in particular can be improved through manual self-tracking using digital interventions that are equipped with BCTs, namely receiving knowledge on how to best lead a healthy lifestyle, learning more about the outcomes of health-related behavior, self-monitoring, and receiving feedback, instructions, or tips [15]. Wearable devices automate both the process of collecting personal data and the act of aggregating insight from the information, leaving users feeling disengaged or detached from their devices [22]. 8 long-term users of the Oura Ring, a wearable designed to monitor sleep, were asked about their experiences with the device, their relationship with sleep, and and their familiarity with the sleep contributors measured by the ring. Their responses revealed a disinterest in the information presented to them, citing that it was not novel compared to what they could discern by themselves through their own subjective feeling. The respondents also reported a sense of helplessness over their capabilities to change their habits or influence the data captured by the device. Despite harboring an interest in sleep tracking and a desire to improve the quality of their sleep, most respondents were unable to define the seven key sleep contributors measured by the ring except for one or two, suggesting that their attention to their data is highly fragmented or selective. We explored the potential reasons for these issues and believe that, rather than weigh the advantages of manual and automated self-tracking, a hybrid approach to data collection that combines both subjective and objective measures is best for capturing a comprehensive picture of a person's sleep [18], [22] as users also make much better sense of their data when they collect it themselves [22]. Making the mobile application more accessible in terms of its language used and its nudging techniques may also better empower users to leverage their data [23].

Acknowledgments

This research was supported in part by JSPS KAKENHI Grant-in-Aid for International Collaborative Research (Overseas Collaborative Research) (23KK0188), JST Trilateral AI (JPMJCR20G3), and the Grand Challenge of the Osaka University Society 5.0 Research Center Support Project.

References

[1] Nolasco, H. R., Vargo, A., Moreeuw, M., Hara, T. and Kise, K.: Augmenting Sleep Behavior with a Wearable: Can Self-Reflection Help?, *Proceedings of the Augmented Humans International Conference 2024*, AHs '24, New York, NY, USA, Association for Computing Machinery, pp. 278–281 (online), DOI: 10.1145/3652920.3653049 (2024).

[2] Nolasco, H. R., Vargo, A., Komatsu, Y., Iwata, M. and Kise, K.: Perception Versus Reality: How User Self-reflections Compare to Actual Data, *Human-Computer Interaction – INTERACT 2023* (Abdelnour Nocera, J., Kristín Lárusdóttir, M., Petrie, H., Piccinno, A. and Winckler, M., eds.), Cham, Springer Nature Switzerland, pp. 665–674 (online), DOI: 10.1007/978-3-031-42286-7 (2023).

[3] Cao, R., Azimi, I., Sarhaddi, F., Niela-Vilen, H., Axelin, A., Liljeberg, P. and Rahmani, A. M.: Accuracy Assessment of Oura Ring Nocturnal Heart Rate and Heart Rate Variability in Comparison With Electrocardiography in Time and Frequency Domains: Comprehensive Analysis, *Journal of Medical Internet Research*, Vol. 24, No. 1, p. e27487 (online), DOI: 10.2196/27487 (2022).

[4] Altini, M. and Kinnunen, H.: The Promise of Sleep: A Multi-Sensor Approach for Accurate Sleep Stage Detection Using the Oura Ring, *Sensors*, Vol. 21, No. 13, p. 4302 (online), DOI: 10.3390/s21134302 (2021). Number: 13 Publisher: Multidisciplinary Digital Publishing Institute.

[5] Chee, N. I. Y. N., Ghorbani, S., Golkashani, H. A., Leong, R. L. F., Ong, J. L. and Chee, M. W. L.: Multi-Night Validation of a Sleep Tracking Ring in Adolescents Compared with a Research Actigraph and Polysomnography, *Nature and Science of Sleep*, Vol. 13, pp. 177–190 (online), DOI: 10.2147/NSS.S286070 (2021).

[6] Lupton, D.: *The Quantified Self*, Polity Press, 1st edition (2016).

[7] Ferguson, T., Olds, T., Curtis, R., Blake, H., Crozier, A. J., Dankiw, K., Dumuid, D., Kasai, D., O'Connor, E., Virgara, R. and Maher, C.: Effectiveness of wearable activity trackers to increase physical activity and improve health: a systematic review of systematic reviews and meta-analyses, *The Lancet Digital Health*, Vol. 4, No. 8, pp. e615–e626 (online), DOI: 10.1016/S2589-7500(22)00111-X (2022). Publisher: Elsevier.

[8] Hutchesson, M. J., Gough, C., Müller, A. M., Short, C. E., Whatnall, M. C., Ahmed, M., Pearson, N., Yin, Z., Ashton, L. M., Maher, C., Staiano, A. E., Mauch, C. E., DeSmet, A. and Vandelanotte, C.: eHealth interventions targeting nutrition, physical activity, sedentary behavior, or obesity in adults: A scoping review of systematic reviews, *Obesity Reviews: An Official Journal of the International Association for the Study of Obesity*, Vol. 22, No. 10, p. e13295 (online), DOI: 10.1111/obr.13295 (2021).

[9] Robbins, R., Seixas, A., Masters, L. W., Chanko, N., Diaby, F., Vieira, D. and Jean-Louis, G.: Sleep tracking: A systematic review of the research using commercially available technology, *Current sleep medicine reports*, Vol. 5, No. 3, pp. 156–163 (online), DOI: 10.1007/s40675-019-00150-1 (2019).

[10] Fuller, D., Colwell, E., Low, J., Orychock, K., Tobin, M. A., Simango, B., Buote, R., Van Heerden, D., Luan, H., Cullen, K., Slade, L. and Taylor, N. G. A.: Reliability and Validity of Commercially Available Wearable Devices for Measuring Steps, Energy Expenditure, and Heart Rate: Systematic Review, *JMIR mHealth and uHealth*, Vol. 8, No. 9, p. e18694 (online), DOI: 10.2196/18694 (2020).

[11] Kuosmanen, E., Visuri, A., Kheirinejad, S., van Berkel, N., Koskimäki, H., Ferreira, D. and Hosio, S.: How Does Sleep Tracking Influence Your Life? Experiences from a Longitudinal Field Study with a Wearable Ring, *Proc. ACM Hum.-Comput. Interact.*, Vol. 6, No. MHCI, pp. 185:1–185:19 (online), DOI: 10.1145/3546720 (2022).

[12] Keys, R., Marshall, P., Stuart, G. and O'Kane, A. A.: "I think it saved me. I think it saved my heart": The Complex Journey From Self-Tracking With Wearables To Diagnosis, *Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems*, CHI '24, New York, NY, USA, Association for Computing Machinery, pp. 1–15 (online), DOI: 10.1145/3613904.3642701 (2024).

[13] Oyebode, O., Alhasani, M., Mulchandani, D., Olagunju, T. and Orji, R.: SleepFit: A Persuasive Mobile App for Improving Sleep Habits in Young Adults, *2021 IEEE 9th International Conference on Serious Games and Applications for Health(SeGAH)*, Dubai, United Arab Emirates, IEEE, pp. 1–8 (online), DOI: 10.1109/SEGAH52098.2021.9551907 (2021).

[14] Choe, E. K., Lee, B., Kay, M., Pratt, W. and Kientz, J. A.: SleepTight: low-burden, self-monitoring technology for capturing and reflecting on sleep behaviors, *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing*, Osaka Japan, ACM, pp. 121–132 (online), DOI: 10.1145/2750858.2804266 (2015).

[15] DeSmet, A., De Bourdeaudhuij, I., Chastin, S., Crombez, G., Maddison, R. and Cardon, G.: Adults' Preferences for Behavior Change Techniques and Engagement Features in a Mobile App to Promote 24-Hour Movement Behaviors: Cross-Sectional Survey Study, *JMIR mHealth and uHealth*, Vol. 7, No. 12, p. e15707 (online), DOI: 10.2196/15707 (2019).

[16] Murawski, B., Plotnikoff, R. C., Lubans, D. R., Rayward, A. T., Brown, W. J., Vandelanotte, C. and Duncan, M. J.: Examining mediators of intervention efficacy in a randomised controlled m-health trial to improve physical activity and sleep health in adults, *Psychology & Health*, Vol. 35, No. 11, pp. 1346–1367 (online), DOI: 10.1080/08870446.2020.1756288 (2020).

[17] Irish, L. A., Kline, C. E., Gunn, H. E., Buysse, D. J. and Hall, M. H.: The role of sleep hygiene in promoting public health: A review of empirical evidence, *Sleep Medicine Reviews*, Vol. 22, pp. 23–36 (online), DOI: 10.1016/j.smrv.2014.10.001 (2015).

[18] Arroyo, A. C. and Zawadzki, M. J.: The Implementation of Behavior Change Techniques in mHealth Apps for Sleep: Systematic Review, *JMIR mHealth and uHealth*, Vol. 10, No. 4, p. e33527 (online), DOI: 10.2196/33527 (2022).

[19] Lin, F.-r. and Windasari, N. A.: Continued use of wearables for wellbeing with a cultural probe, *The Service Industries Journal*, Vol. 39, No. 15-16, pp. 1140–1166 (online), DOI: 10.1080/02642069.2018.1504924 (2019). Publisher: Routledge.

[20] De Cristofaro, D. and Chiodo, S.: Quantified Sleep: Self-Tracking Technologies and the Reshaping of 21st-Century Subjectivity, *Historische Sozialforschung = Historical social research*, Vol. 48, No. 2, pp. 176–193 (online), DOI: 10.12759/hsr.48.2023.21 (2023).

[21] Baron, K. G., Abbott, S., Jao, N., Manalo, N. and Mullen, R.: Orthosomnia: Are Some Patients Taking the Quantified Self Too Far?, *Journal of Clinical Sleep Medicine*, Vol. 13, No. 02, pp. 351–354 (online), DOI: 10.5664/jcsm.6472 (2017).

[22] Choe, E. K., Lee, N. B., Lee, B., Pratt, W. and Kientz, J. A.: Understanding quantified-selfers' practices in collecting and exploring personal data, *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '14, New York, NY, USA, Association for Computing Machinery, pp. 1143–1152 (online), DOI: 10.1145/2556288.2557372 (2014).

[23] Lazar, A., Koehler, C., Tanenbaum, T. J. and Nguyen, D. H.: Why we use and abandon smart devices, *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing*, UbiComp '15, New York, NY, USA, Association for Computing Machinery, pp. 635–646 (online), DOI: 10.1145/2750858.2804288 (2015).

[24] Marcengo, A., Rapp, A., Cena, F. and Geymonat, M.: The Falsified Self: Complexities in Personal Data Collection, *ResearchGate*, (online), DOI: 10.1007/978-3-319-40250-5 (2024).

[25] Clark, M., Southerton, C. and Driller, M.: Digital self-tracking, habits and the myth of discontinuance: It doesn't just 'stop', *New Media & Society*, Vol. 26, No. 4, pp. 2168–2188 (online), DOI: 10.1177/14614448221083992 (2024).