Sleep Experiments. Knowledge Production through Self-Tracking

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Abstract: *»Schlaf-Experimente. Wissensproduktion im Self-Tracking«.* Scientific knowledge is a central point of reference for almost all everyday activities – and at the same time, it is doubted more than ever. People who suffer from sleep problems, for example, thus often lack clear instructions because the scientific findings on the subject are fragile and contradictory. Against this background, we treat the digital self-tracking of expertized laypersons as an experimental practice undertaken to reduce uncertainty. Our online ethnography suggests that self-tracking involves at least three prerequisites to reduce uncertainty in everyday life. First, such self-tracking requires, in its interplay of objectivity and subjectivity, a willingness to engage in tinkering and tuning. Second, corresponding arrangements involve a specific form of temporality, continuously linking the past to an open future. And third, through grafting, a continuous expansion of self-tracking arrangements takes place, ultimately leading to a form of knowledge-in-the-making that relates to science but works in everyday life.

Keywords: Self-tracking, sleep, uncertainty, knowledge production, experimental systems, Quantified Self, biohacking.

1. Introduction

Digital technologies related to sleep – ranging from activity trackers and watches to smart rings, heart rate belts, and sleep trackers that are placed under the sheets or attached to the head and capture eye movements or electroencephalogram signals – have become established in recent years (Sovijärvi, Arina, and Halmetoja 2017, 39; Lyall and Nansen 2023, in this issue). Tracking your own sleep with these technologies is usually dedicated to individual questions and problems. Through digital sleep tracking, patterns in

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one's own behavior should be recognized and corresponding effects understood, making it possible "to make changes to our behavior in order to become a better or successful sleeper and improve quality of life" (Williams, Coveney, and Meadows 2015, 1047). In the case of sleep tracking, the apps lead to the availability (Meißner 2021) or evidence of sleep (Hine, Meadows, Pritchard 2023, in this issue) in the form of numbers and curves – they lead to the production of sleep knowledge.

In the following, we explore the question why this self-generated knowledge about one's own sleep seems so valuable for a growing number of self-trackers when today's sleep medicine and sleep research simultaneously produce comprehensive and very elaborate scientific knowledge about sleep that is published in numerous manuals and guidebooks. In our contemporary society, the role of (scientific) knowledge is constantly emphasized. In such a "knowledge society" (Drucker 1969; Stehr 1994), scientific knowledge shapes everyday life to a great extent. Nevertheless, this scientification of everyday life is not usually associated with any gain in certainty. On the contrary, science is less a provider of reliable knowledge than a source of uncertainty (Stehr and Grundmann 2010, 97; Callon, Lascoumes, and Barthe 2011, 18). Thus, scientific knowledge in everyday life is ascribed greater relevance than ever before, while at the same time, it is doubted more than ever (Beck 1986, 2007). Coping with uncertainty, then, represents a central challenge (Nowotny 2016, xiii).

The conflicting, tentative, and uncertain nature of scientific knowledge can be observed in the health field: anyone who questions which scientific knowledge should be applied concerning their own diet, exercise, or even sleep will encounter differing, sometimes contradictory, scientific findings. Scientific knowledge about sleep, for example, proves conflicted regarding what constitutes a sleep disorder while failing to identify specific standards for regulating individual sleep behaviors (Kroker 2015; Ahlheim 2018). Furthermore, clinical advice points out that it is difficult to find normative statements about sleep: for example, no definitive statements on minimum sleep duration can be made (Crönlein 2018, 26), and the causes of sleep problems and disturbances also cannot be simply determined or causally clarified (Wolf-Meyer 2012, 7). Accordingly, scientific knowledge is not regarded as an unquestionable, unambiguous, and action-guiding basis for (re)finding undisturbed sleep. The starting point of our epistemological considerations is thus the question how laypeople can address the uncertainty of scientific knowledge in their everyday lives.

Epistemic uncertainties can be addressed in quite different ways. The possibilities include, for example, consulting experts (Stehr and Grundmann 2010), quantifying risk calculations (Beck 2007; Esposito 2014), practicing prevention, and taking precautions (Callon, Lascoumes, and Barthe 2011). While these strategies aim to reduce uncertainty, some, such as fatalism, ignorance,

hope, or faith, presuppose the acceptance of uncertainty (Zinn 2008; Zirfas 2015). Otherwise, Zinn (2008, 2016) further understands relying on intuition or trust as "in-between strategies" for coping with uncertainty, whereby the building of resilience (Bonß 2015) could possibly be added here. Using digital sleep tracking as an example, we conceptualize the experimental production of individual knowledge as a specific form of uncertainty reduction.

In the following, we treat the digital self-tracking of expertized laypersons as an experimental practice undertaken to reduce uncertainty in everyday life.[1] Thus, we assume that the use of digital sleep tracking technologies can be analyzed in alignment with Rheinberger's concept of "experimental systems," which we will elaborate on in the next chapter. Against this background, we then explain our online ethnographic approach and the empirical material used in this study. The empirical investigation suggests that digital self-tracking is an experimental form of uncertainty reduction that has at least three distinctive features: it (1) entails a specific attitude of the self-researcher resulting from the remediation of an uncertain situation; (2) is situated in a temporal openness in which self-tracking data always aim at inferring the future by recourse to past data but also always carry the potential for generating new knowledge; and (3) involves an enhancement and expansion of the self-tracking arrangement, scaling the experimental system.

2. Sleep Tracking Arrangements as "Experimental Systems"

In the *Biohacker's Handbook*, the authors state that biohackers understand the "body as a complex system that can be probed, analyzed, understood, and put to test. Such controlled experimentation (i.e., biohacking) can be used to pursue self-development and deeper self-understanding" (Sovijärvi, Arina, and Halmetoja 2017, 6). This experimental access to one's own body can be linked to sociological analyses of the present. A series of sociological studies claim that a knowledge society acquires experimental characteristics (Bogusz and Reinhart 2018; Krohn and Weyer 1989; Groß and Krohn 2005; Marres 2017) and can be seen as a "society of self-experimentation" (Groß, Hoffmann-Riehm, and Krohn 2005, 14). Technologies play a central role here, which is why numerous sociological studies address digital self-tracking as a primarily scientific and experimental practice (e.g., Greenfield 2016; Heyen 2016, 2020; Lupton 2016; Rettberg 2014; Swan 2013; Unternährer 2016; Zillien, Fröhlich,

[1] Especially in the internet age, many people who are affected by health problems not only have specific "experiential knowledge" but also acquire comprehensive medical expertise (Akrich and Rabeharisoa 2021), which is characterized by the terms "expertized laypersons" or "lay experts" (Epstein 1995).

and Dötsch 2014; Zillien and Fröhlich 2018; Zillien 2020). From an epistemological perspective, our research shows that digital self-tracking comes with the promise of objective, neutral, and unbiased feedback about user behavior (Strübing, Kasper, and Staiger 2016, 278; Unternährer 2016, 215). Accordingly, digital self-tracking is linked to the epistemological ideal of subjectless objectivity. In this view, knowledge is considered objective if its production is uninfluenced by prejudices or abilities, fantasies, judgments, desires, or ambitions, which can be linked to the principle of "mechanical objectivity" (Daston and Galison 2007, 127). This principle states that the influence of the research subject in the production of knowledge should be minimized using standardized procedures that are thus understood as objective. Accordingly, the use of digital technologies strengthens the perception of the objectivity of the knowledge produced. At the same time, self-trackers are concerned with the investigation of exactly one very specific, maximally subjective case: their own. This interplay of subjectivity and objectivity in the context of self-tracking projects is pointedly expressed by their description as "n of 1" experiments (Greenfield 2016, 125) or also as "personal science" (Heyen 2020; Wolf et al. 2022). The latter is also the title of a book that currently summarizes (in a preliminary online version) key findings of the Quantified Self community and describes the interplay of objectivity and subjectivity as follows:

> We focus attention on our own experience: that is, we observe ourselves. At the same time, we set and follow some rules for recording what we notice, rules that make our conclusions more trustworthy and our insights more legible. (Wolf et al. 2022, 9)

More generally, this mode of knowledge production is aptly outlined by Hans-Jörg Rheinberger (2002 [1997], 2010, 2021), who essentially shows that ongoing experimental work in the science laboratory leads from a situation of uncertainty to new, robust knowledge. Rheinberger's term "experimental system" describes complex, continuously developing arrangements that aim to produce new knowledge and consist of the instruments and measuring devices used, the research personnel and their skills, the laboratory architecture, and the object of investigation. Thereby, Rheinberger ascribes great importance to "technical things" (Rheinberger 2002 [1997], 25f.), which denote materialized knowledge that has been realized, for example, in technologies, terms, or models. Moreover, technical things guarantee the stability of experimental systems, thus enabling the replicability of the experimental setup and the comparison of varied experiments over time. On the other hand, an "epistemic thing" (Rheinberger 2002 [1997], 24ff.) is the indeterminate object of research and presents itself in characteristic vagueness, which is not understood as a deficit but rather as an engine of experimental work. Experimentation, on this understanding, consists of the ongoing interplay of technical and epistemic things, whereby "technical things set the boundary conditions of experimental systems and in the process create the space in

which an epistemic object can unfold" (Rheinberger 2010, 218). Epistemic things, then, emerge only in an ongoing confrontation with the resistances of technical things, gradually gain shape, solidify, and can eventually become technical things themselves. Nevertheless, there must be enough leeway to ensure that experimental knowledge production does not proceed purely mechanically: that is because overly rigid experimental systems can produce only replicas and thus cannot lead to new knowledge (Rheinberger 2002 [1997], 84). Consequently, an experimental system "in which a scientific object gradually takes on contours in the sense that certain signals can be handled in a reproducible way [...] has to simultaneously open windows in which new signals are visible" (Rheinberger 2012, 95). Therefore, experimental systems strive for "differential reproduction" (Rheinberger 2002 [1997], 76ff.) to produce new knowledge by a continuous variation of the experimental arrangement stabilized by technical things. Based on Rheinberger's epistemological approach, our illustrative analysis of sleep tracking projects focuses on the question how experimental knowledge production reduces epistemic uncertainty.

3. Methods

Our findings are based on a digital ethnographic analysis (Hine 2015; Pink et al. 2016) of digital communities of sleep trackers. Since 2020, we have been lurking in online forums, blogs, and subreddits devoted to sleep-tracking individuals, primarily from the ranks of the Quantified Self movement, biohackers, and producers of sleep-tracking technology. Furthermore, we analyzed online video footage on sleep tracking from meetups of the Quantified Self and biohacking movements as well as video reviews about the apps and devices in our sample. Following the principle of theoretical saturation (Glaser and Strauss 1967), we researched, read, and discussed relevant online material until we could locate no further data that would have enriched our understanding of knowledge production through sleep tracking. Successively, we made a material selection of 16 blog posts from personal blogs of self-trackers about gathering and interpreting data as well as nine threads on Reddit posted by members of those communities discussing sleep, sleep tracking, biohacking, polyphasic sleep, and sleep-tracking devices. These self-reports and online discussions are characterized primarily by the presentation of self-trackers' own data and experiments as well as debates over influencing factors and sleep improvement. We also analyze a total of 26 videos; nine are from Quantified Self community meetings from 2011 to 2016 and are freely

available on their website[2]; ten videos are reviews and comparisons of sleep tracking devices from 2019 to 2021 that are publicly available on YouTube; and another seven videos include recordings of the Biohacker Summit from 2016 to 2019 that were marketed by the conference organizers. The videos include laypeople presenting their own data, especially in the Quantified Self community corpus, as well as scientific experts and entrepreneurs, especially in the biohacking community collection of materials. While the Quantified Self community is focused mainly on producing "self-knowledge through numbers," the biohacking scene takes a more holistic approach, adding natural living concepts and achieving resilience through the use of cutting-edge technology (Sovijärvi, Arina, and Halmetoja 2017). Even though the cases we analyzed involve primarily laypeople, it must be noted that their ongoing self-expertization gives them a more in-depth approach to their sleep and data than is the case with most everyday life users of sleep-tracking gadgets. To complement this source, we also included manuals from both movements in our data analysis, giving us access to their principles and ideas (Sovijärvi, Arina, and Halmetoja 2017; Wolf et al. 2022).

For research ethics reasons, we considered only internet forums and websites that were publicly discoverable and accessible – i.e., discoverable via search engines and not requiring logins or passwords for access (Heise and Schmidt 2014, 528; Döring 2013, 311). Following grounded theory, we exported and saved the online material and transcribed all videos for further qualitative analysis (Glaser and Strauss 1967; Strauss 1987). Given the public nature of the material, we decided not to pseudonymize the authors or paraphrase the entries. By using the nicknames of self-trackers, we account for the users' anonymization strategies.

In the following investigation, we include our empirical material entirely but devote more detailed attention to three specific sleep-tracking projects. Thus, we analyze three online blog entries in considerable depth and present the corresponding sleep-tracking projects in a case-analytic manner, reconstructing the process of knowledge production and the associated practices of uncertainty reduction.

4. Empirical Investigations

The following case studies are devoted to ambitious projects undertaken by self-trackers who belong to the Quantified Self community or call themselves biohackers and thus are "lay people or citizens, at least no professional scientists, [who] use methods and procedures known from science such as

[2] Quantified Self, "What is Quantified Self?" www.quantifiedself.com/about/what-is-quantified-self/ (Accessed November 24, 2022).

research design, data collection or data analysis in order to produce knowledge for self-use in their daily lives" (Heyen 2020, 125). Although these cases differ significantly, each project can be understood as an "experimental system" in Rheinberger's sense. In this respect, each case study illuminates its own aspects of the experimental production of knowledge. The first case study highlights a typical course of a repetitive self-tracking project, the second case conceptualizes self-tracking as an ongoing interplay between technical and epistemic things, and the third case underscores the principle that an experimental system can be continuously expanded and adapted to changing conditions. These cases do not form ideal types but are instead case vignettes that help us clarify our theoretical model. Overall, self-tracking practices are treated as experimental systems that strive for certainty.

4.1 "Will I Ever Get a Good Night's Sleep Again?" – Uncertainty as a Starting Point

The starting point of many sleep tracking projects is the problematization of one's own sleep and, thus, a situation of uncertainty (Alqahtani, Jay, and Vigo 2020, 1813). Generally, at first, self-trackers "become aware of and concerned about some set of repeated or ongoing sensations (such as pain, fatigue, digestive issues, sleep issues, mood issues, etc. etc.)" (Wright 2018, 1002). Thereby, the starting point is already committed to the principle of "n of 1" because the questions underlying the self-tracking projects are "so closely inter-woven with individual experience and context that even the terms of the personal questions may be hard for strangers to understand" (Wolf et al. 2022, 11). In this sense, blogger *Trainer Andrei* was driven to track his sleep because of the upcoming birth of his child. Andrei tried to prepare for the expected nightly interruptions during the run-up to the birth because he "was getting plenty of warnings about how much sleep I'd lose." As a first step, Andrei's wife tried to prepare him for the expected sleep interruptions by waking him up in the middle of the night, but this was not working. For this reason, Andrei resorted to digital technologies and initially aimed to wake up in a controlled manner during his light sleep phase so that the sleep interruptions did not disturb him inordinately. For this purpose, he uses the "Sleep Cycle" app, an alarm clock app that measures sleep. The app "allowed me to set my 'waking window' and have an alarm activate when I entered a light sleep phase." With this app, Andrei was able to see the first positive results:

> Instead of being jolted out of my deep sleep and being pissed off for the rest of the day, my new app would gradually wake me between a specified time range. It felt more natural and refreshing. Sometimes I'd even get less sleep than my wife, but I felt more energetic and was in better mood throughout the day.

Here, the problematization of sleep and the use of media technology to objectify sleep enables Andrei to develop a first approach to understanding his own sleep behavior. Sleep thus appears here as an epistemic thing that raises new questions and possibilities through the first findings. As a first step, the app helps him wake up in a corresponding sleep pattern, which makes him feel more rested – despite getting less sleep than his wife. Andrei integrates his subjective feeling to validate his results and gain robust knowledge of his actions. At the same time, the technological measurement of his sleep shows that his strategy works only if he falls asleep two hours before the alarm, which is not necessarily likely in the corresponding constellation. Therefore, after the birth of his child, he decided to try other techniques to get the sleep he needs and to track his sleep. He recorded his sleep on 288 days over a 12-month period and "learned [...] much about myself, my sleeping habits and what it takes to get through the night when you have a newborn in the house." In his blog, Andrei then comprehensively discusses his data and the lessons learned:

> I suffered. Not only was the amount of time spent in bed [...] short but my normal sleep patterns are non-existent, hence the 29% quality rating. Compare my worst night to my best night. During my best night I achieved 100% by spending nearly 10 hours in bed and going into very deep sleep 3 times. For the first 9 and some hours the sleep was uninterrupted until the morning when my internal clock started going off. I assure you, I had way more "worst nights" than "best nights."

Through tracking, Andrei discovers that he is not sleeping enough and that his usual sleep pattern has been destroyed, even though sleep depth and duration determine his well-being the following day. Starting with the uncertainty regarding whether he will ever sleep well again, Andrei relies on measures of sleep analysis inscribed in the app, representing a railing he can shinny up. Then, referring back to his app, he starts to analyze the effects of daily activities and events, such as drinking chamomile tea, eating late, daily stress, showering before bed, working out, or engaging with electronics and TV before bed. Finally, Andrei is able to reveal which factors benefit his sleep even after the birth of his child, generating surprising findings, such as the positive effects of using electronic devices:

> I'm sure you've heard doctors, sleep experts, and media advise to avoid electronics or watching TV before going to bed to ensure a good night's rest. I'm glad I avoided that advice. The use of electronics before bed or watching TV actually helped me get a good night's rest. I am not suggesting you'll experience the same effect, but using sleep notes will help you figure what works or doesn't for you.

Through continuous self-experimentation, Andrei works out an experimental system with which he can specifically shape his individual sleep behavior. In this way, the extent to which an experimental system produces new knowledge over time – following Rheinberger (2012, 94) – depends on

"whether one manages to produce differences without destroying its reproductive coherence." Rheinberger calls this process "differential reproduction," which is "a kind of probing movement which with regard to the scientific object can be described as a 'jeu des standard' or a 'game' of difference" (Rheinberger 2012, 94). On the researcher's side, this "tentative search for differences" (Rheinberger 2002 [1997], 77) requires experience – respectively "something that can perhaps best be paraphrased using the paradoxical expression 'acquired intuition'" (Rheinberger 2012, 95). In a continuous interplay of objectifying technologies and highly subjective insights, Andrei's sleep scores improve gradually, an outcome that he attributes not only to the baby's better sleep patterns but also to the routines he has developed for managing sleep disorders. In the end, Andrei's experimental system works so reliably that when sleep interruptions occur again, for example while his baby is teething, all he has to do is put his proven routines to use. Andrei's sleep-related knowledge, then, is self-related, considered certain, and thus of practical use in everyday life (Heyen 2020, 130). In this specific constellation, Andrei is no longer concerned with continuously generating new knowledge in the experimental system. Rather, the knowledge that has already been tested is to be applied in a controlled manner to produce the desired effect: restful sleep. There are also, however, constellations of sleep tracking that are less stable and evolve over time as new questions constantly arise, which is the focus of the following case study.

4.2 "Comparing HRV is Tricky, But You Should Monitor Your Own Average" – Ongoing Experimentation

The economist, athlete, and biohacker Ilmo Stromberg documents various bio-hacking and self-tracking projects on his online blog, whereby four projects focus intensively on sleep. Ilmo has been using a sleep tracking ring from Oura and is also a user of Somnofy, a non-contact sleep tracking technology that collects environmental data such as noise, light, and air quality near his bed. The following analysis focuses on his first sleep-related report, which examines the recovery value of his nighttime sleep using data from his sleep tracking ring from the preceding thousand days.

The key metric in Ilmo's blog post is so-called heart rate variability (HRV), which indicates the average time interval between two consecutive heartbeats in milliseconds. Usually, high HRV values are interpreted as a sign of greater adaptability to physical or mental challenges and, thus, as an expression of recovery and fitness. As pointed out in the online information on the Oura ring , however, "'high' and 'low' HRV is relative for each person." Thus, the measured value is highly individual, not very intuitive, and challenging to interpret.

To get to the bottom of his HRV values, Ilmo systematically studies their meaning in various experimental setups for nearly three years. For example, he relates his HRV values from "normal situations" to his values after a half marathon, binge drinking, and a fever. In the long run, he analyzes which other indices correlate positively or negatively with his HRV values and focuses on the relationship between well-being and HRV. Ilmo knows that "comparing HRV is tricky, but you should monitor your own average." Gradually, he becomes more confident in interpreting his values, which comprehensively increases their analytical significance. After a thousand measured days, he states: "For me, as an athlete, it's an important variable to monitor. I want to train hard but avoid overtraining. Nighttime HRV values give me a good signal for the day: how hard should I push in training today?" The HRV now functions as a robust measure indicating how well his body has recovered overnight, guiding his training schedule. Based on what he did the previous day, he can even estimate the value quite precisely. For Ilmo, heart rate variability is now "the most important value from Oura Data," which he meanwhile knows so well that he can confidently adjust the scope for interpretation:

> My average HRV is 70, and it normally fluctuates +- 10. I take it easy with training if my HRV is under 60, but it's not a strict rule. For example, there's no reason to skip training today if I ate the previous day's late-night meal, which affects HRV negatively.

Ilmo has elicited individual thresholds for himself, but he interprets them according to the situation. His in-depth knowledge of the conditionality of his HRV gives him a relaxed and confident approach to understanding his own data. Ilmo takes advantage of this in later self-experiments, too. For example, the blog post "I had low HRV for a few months – What happened, and how did I bounce back?" reports an unclear drop in HRV value, which Ilmo first worriedly interprets as an indication of COVID disease or a cat allergy. But a self-experiment proves that after all he was obviously just exercising too intensively: "Based on data, it's safe to say that intense and frequent training decreased my HRV. We can use Occam's razor here: The simplest explanation is usually the right one." In this later self-experiment, Ilmo no longer has to trace the correct interpretation of the vague, highly individual, and difficult-to-interpret HRV values. On the contrary, he uses the HRV values, which are now robust in his specific case, as the guardrail for his knowledge gain.

At first, Ilmo treated HRV as an epistemic thing. Then, in numerous self-experiments, he carefully felt his way toward the not entirely simple interpretation of the measured value – and HRV evolved into a technical thing. In this case, "a standard scientific object itself becomes a tool, a technical construct, which makes it possible to new research arrangements" (Rheinberger 2012, 96). Finally, Ilmo is able to control his HRV values specifically. At the end of his blog post, he lists dos and don'ts regarding how he can at least

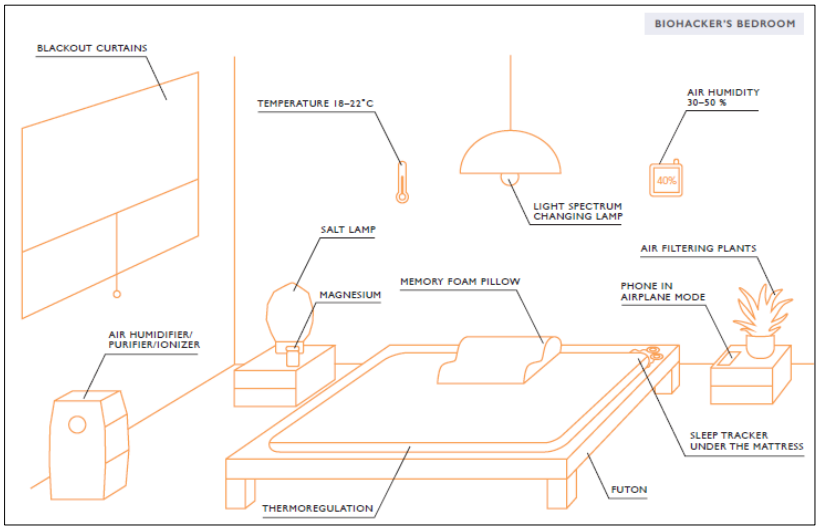
ensure that he experiences good HRV values. Thus, an epistemic thing has successively become a technical thing, which keeps the experimental system running. Yet the reverse is quite conceivable: technical things can also "become epistemic things or help produce them – for example, if they elicit unexpected questions in their use" (Rheinberger 2010, 218). In this sense, technical things can also lose their quasi-ontological status at any time. This ongoing interplay between technical and epistemic things illustrates that experiments are constantly in motion and open to the future. This specific temporality also affects the composition and number of experimental elements, on which we elaborate in the following case study.

4.3 "Not Every Idea Can or Should Be Useful" – Localizing and Expanding

The writer and biohacker Gwern discusses a range of topics on his blog, "from statistics to psychology to self-experiments/Quantified Self to philosophy to poetry to programming." To track his sleep patterns, Gwern uses a Zeo headband that collects "reasonably accurate" data on how various medications, activities, or changes in location affect his sleep. On his blog, there is a main post about his self-experimental engagement with sleep, which is gradually supplemented by further posts, whereby the corresponding observations, experiments, and studies are sometimes more and sometimes less detailed. Typically, Gwern poses a question, collects a large amount of sleep-related data, transfers it to Excel, and exports it into the statistical program R for analysis. Following Gwern, his experiments must always yield relevant "value of information (VOI)." The purpose of knowledge obtained via self-tracking is thus to improve one's quality of life while simultaneously weighing the cost–benefit ratio: "If gathering data is too hard and would make your life worse off – then don't do it!" Gwern describes his self-tracking experiments as follows: "1) Have an idea; 2) Collect data; 3) Test the data; 4) Make a change, GOTO 1." Thus, he repeats this process until the expected information value no longer matches the cost. His ongoing experimentation is characterized by the constant expansion of his experimental system. Starting from the current arrangement, he permanently tests new ideas, methods, and technologies, evaluates these factors concerning the "value of information," and correspondingly incorporates or eliminates the respective elements: "To model sleep effects, I want to take into account bedroom temperature, humidity, CO_2, sound, and measure sleep." For example, he adds new technologies to his experimental system on a test basis, such as an air-quality sensor, a fan, and a red-light lamp, or studies the effects of new procedures, such as sleeping in a hammock or standing on one leg before going to bed. This "insertion of new apparatuses or procedures into an already existing experimental system" Rheinberger (2021, 94) calls "grafting." In contrast to the modification

of existing elements or the dissolution of previous components in a hybridization, grafting "should bring its own potential to light with the help of the base and at the same time leave this base intact in its functioning" (Rheinberger 2021, 105). The following graphic from the *Biohacker's Handbook* (Sovijärvi, Arina, and Halmetoja 2017, 27) shows the possibilities of grafting in a sleep tracking project when looking only at bedroom conditions: for example, the lighting conditions, humidity, or room temperature can be changed experimentally, but this requires adding a new apparatus to the experimental system in each case.

Figure 1 Bedroom Settings in the Sense of Biohacking



Source: Sovijärvi, Arina, and Halmetoja 2017, 27.

In this sense, Gwern's experimental base is the Zeo sleep tracking arrangement, which he gradually grafts, whereby the graft must "deliver a characteristic result for this extension on the epistemic side. Otherwise, it would not be worth the effort" (Rheinberger 2021, 109). Or, as Gwern puts it: "The value of an experiment is the information it produces."

In a continuous process, Gwern successively incorporates additional elements into his experimental setup, whereby the retention of a graft often results in additional extensions. For example, using the air-quality sensor, Gwern discovered "that closing my bedroom tightly to reduce morning light also causes CO_2 levels to spike overnight to 7x daytime levels." To determine adverse outcomes of high CO_2 levels, Gwern added a fan to his experimental setup as "better ventilation may improve sleep quality." On the other hand, he removes technologies or procedures that add nothing to the value of

information, such as sleeping in a hammock or standing on one leg, which is consistent with his statement that "not every idea can or should be useful." Thus, a technology or procedure can not only be grafted but also "degrafted" if it does not promise further clarification of the experimental system.

5. Discussion

As different as the three above-described sleep tracking projects may be in detail, the goal in each case is to gain valid knowledge through an experimental approach. That is, Andrei, Ilmo, and Gwern use digital technologies in a self-experimental way to produce sleep-related knowledge that, on the one hand, draws on science but, on the other hand, is of practical use in their individual everyday lives. As we explain in the following, this digital mode of experimentally producing robust knowledge has at least three distinctive features.

First, in their interplay between objectivity and subjectivity, self-tracking experiments require a specific attitude on the part of the self-researcher. As self-tracking "invites the subject to turn inward, becoming both subject and object of her own data-driven inquiry" (Greenfield 2016, 128), digital self-tracking as an experimental practice is characterized by a specific proximity of research subject to research object (Zillien 2020), which makes it challenging to create an "epistemological rupture" (Bachelard 1988). Because of the specific proximity of research subject and research object, self-tracking diametrically contradicts the scientific ideal of objectivity, which regards any subjectivity in the process of scientific knowledge acquisition as a source of "philosophical trouble" (Shapin 2012, 171). At the same time, however, self-tracking practices are characterized by a striking degree of objectivity insofar as the quantification and formalization processes inscribed in digital technologies enable the establishment of a distanced observer position. In reflections on her own self-tracking project, Anne Wright accordingly states that self-trackers

> seek out and iterate on a combination of medical engagement and other potential methods and models while developing and refining an internal sense of evaluation (Is this helping or not? Do I feel different? How? What do the concerning sensations mean in this new context?). (Wright 2018, 1002)

Self-tracking, then, constitutes experimental interplay between objectifying technologies and "an individual's sense of self" (Wright 2018, 1009). In addition to Rheinberger's approach, there are other epistemological studies that investigate this interplay more generally. With his concept of a "mangle of practice," Andrew Pickering, for example, claims that in experimental knowledge production, "disciplined human agency and captured material agency are [...] constitutively intertwined; they are interactively stabilized"

(Pickering 1995, 17). He compares this continuous adjustment, calibration, and reciprocal stabilization in the experimental setting to a radio station search and speaks of "tuning" (Pickering 1995, 14). Karin Knorr Cetina (2002 [1984], 64ff.) furthermore claims that researchers act as "tinkerers," who perform a kind of skilled patchwork in experimentation. Ian Hacking further emphasizes the "mindfulness" of the experimenter and thus aims in particular at skills in managing and utilizing scientific technologies: "Only if one is mindful will it be possible to make the devices work" (Hacking 1996, 279). Therefore, sleep tracking as an experimental practice requires experience, virtuosity, and artistry in dealing with one's own experimental system – or, in Rheinberger's words (2012, 95), "acquired intuition."

Second, self-tracking projects carried out by expertized laypersons often include a specific form of temporality: they are designed to be ongoing over long periods because experimental systems produce knowledge in the context of time series. Current sleep tracking practices thus link data collected in the past to a future that is understood as successively shapeable. Accordingly, Gary Wolf claims that self-trackers simultaneously look in two directions, "dropping reminders along the way in anticipation of returning, like Hansel with his crumbs. As artifacts, collections face backward, but as an activity, collecting is acquisitive and speculative, encompassing the future" (Wolf 2016, 72). According to Rheinberger, experimental systems are historically conditioned, situationally bound, and open to the future. The principle of differential reproduction maintains the future-related openness of experimental systems even as the technical setup becomes increasingly permanent and standardized. Thus, self-tracking arrangements are established, applied, and thereby constantly modified, which Rheinberger calls "wandering" (2021, 155): all elements and configurations of an experimental system can potentially change their places and are, therefore, by no means fixed forever. Thus, digital self-tracking produces knowledge-in-the-making.

Third, in the digitally mediated conditions of self-tracking, the grafting of experimental systems can be realized particularly effectively. In digital settings, viable interfaces connect technologies, procedures, and epistemic things "in a fertile analytical constellation" (Rheinberger 2010, 217f.). Digitalization and quantification produce commensurability (Espeland and Stevens 1998), which enables grafting, correlation, intertwining, and variation in the experimental setting. Thus, it is generally rather easy to successfully expand an experimental system in the digital realm. For knowledge production in sleep tracking, for example, the tracking device has to be productively connected to the sleeping body. That means the ring or headband must be able to record bodily processes and map them in the form of data. Interfaces then create a digital body (Funken 2005, 220) or, respectively, a "body of numbers" (Zillien, Fröhlich, and Dötsch 2014).

6. Conclusion

The expertized and ambitious sleep trackers we analyzed have turned their lives into experiments. They reduce uncertainties by investigating their own everyday lives experimentally and with (more or less) scientific-technical means. In this way, they produce knowledge that, on the one hand, draws on science but, on the other hand, also proves to be suitable for everyday use.

Still, not all digital self-tracking practices reduce uncertainties or lead to problem-solving (De Cristofaro and Chiodo 2023, in this issue). It is, therefore, by no means to be assumed, in a technologically deterministic manner, that the use of digital technologies alone is a practice that invariably reduces uncertainty. Self-tracking as an experimental practice for reducing uncertainty requires at least three features. First, to reduce uncertainties in everyday life, self-tracking practices necessitate in the interplay of objectivity and subjectivity a specific attitude on the part of the self-researcher, which can be described as "an individual's sense of self" (Wright 2018, 1009) or an "acquired intuition" (Rheinberger 2012, 95). Long-term processes of tinkering and tuning are involved, reducing uncertainty over time. In this way, successive arrangements are continually tested, modified, discarded, or expanded until individual (sleeping) routines are working. Thus, second, experimental practices undertaken to reduce uncertainty require a specific form of temporality. Corresponding tracking arrangements are designed as long-term projects that continuously link the presumptuous past with an open future. The temporal openness of experimental arrangements lies, however, not only in their temporal specificity but also in their systematic expansion by grafting. Third, through grafting, continuous expansion of self-tracking arrangements takes place, ultimately leading to ever-changing knowledge-in-the-making, which nevertheless works.

Thus, we understand the experimental knowledge production of expertized self-trackers as an expression of a pragmatist "thought style" (Fleck 1980 [1935]). Following the aforementioned book *Personal Science*, "chief among these principles is that self-tracking is a basis for valid knowledge" (Wolf et al. 2022, 13) – at least in the here and now.

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