Subjective sleep quality monitoring with the hypnos digital sleep diary

Subjective Sleep Quality Monitoring with the Hypnos Digital Sleep Diary: Evaluation of Usability and User Experience

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Abstract: Sleep diaries are records of individual's sleep and wake times, extending over a period of several days up to several weeks. Sleep diaries are often used to support the diagnosis and treatment of sleep disorders though the emergence of self-tracking technologies also makes them interesting for intrinsically motivated individuals who wish to gain insight into their sleep patterns and related influences. This paper introduces Hypnos, a digital sleep diary, and a user study aimed to its usability and the resulting user experience. The study involved eighteen participants without a diagnosed sleep disorder for a period of ten days. Overall Hypnos was found useful and usable which supports its application in practice, but it is advisable to make the user experience more attractive, stimulating and innovative in order to also make the self-tracking more intrinsically motivating.

1 INTRODUCTION

One third of our lives is spent sleeping. Sleep is the activity that occupies most of our time. However, sleep is not a smooth experience for everyone. In a study (Van de Straat, 2015), an average of 24.2 % of total European population reported to have been bothered by sleep problems in the past six months. Sleep problems are disruptions in the systematic functioning of sleep which further has an impact on the normal physical, mental, social and emotional functioning of individuals.

Sleep problems are identified by specialists and categorised under several classes of sleep disorders. In order to diagnose and treat sleep disorders, sleep diaries, among other tools have been invented. Sleep diaries are records of individual's sleeping and waking times during a period of several days up to several weeks. The information can be written as text or can be represented graphical, and requires to be structured in accordance with the framework of the diary. They are often used in clinical setups for diagnosing and treating sleep disorders, but they can also be used by individuals to be more aware of their sleep experience and to monitor parameters that relate to their sleep. There are many sleep diaries in use by specialized sleep disorders clinics, each of them with its own framework for filling in the data in the diary.

Paper sleep diaries have a few shortcomings to mention: they do not prevent filling in extraneous information outside the framework (e.g., comments, and events other than those expected), it is not possible to know when the diary has been filled in (e.g. a patient can complete the paper diary for a whole week the day before seeing the physician), paper documents can be easily lost, etc.

Given the high adoption of mobile devices and given that today's state of the art mobile devices have large memory storage, high computational power, built in sensors and advanced connectivity possibilities it is likely that pen-and-paper diaries will become a tool of the past, making way to electronic sleep diaries. According to a recent study (Zenith, 2017), in 2018 66% of individuals from fifty-two key countries will own a smartphone, an increase of 3% from 2017 and 8% increase from 2016 tablet ownership is stabilising at 20% of the population, partly because they are more likely to be shared in households, and partly because consumers prefer to user larger smartphones instead.

The purpose of this paper is to describe the design of Hypnos, a digital sleep diary, and to discuss the

results of the usability and user experience evaluation.

2 RELATED WORK

The initial diagnosis of sleep disorders is traditionally made by a primary care physician (Blake, 2010). If needed, the primary care physician will guide the patient towards a specialised institution that will have the expertise to provide adequate treatment.

Sleep specialists use sleep diaries for tracking patterns of sleep, usually for a period of fourteen nights. Currently sleep diaries are mostly paper based. There are many such sleep diaries in use. One such diary is Karolinska Sleep Diary (Akerstedt, 1994). This diary contains twelve items, of which most of them offer a scale graded from five to one. Sleep diaries are valuable tools for the assessment of sleep because they provide a subjective overview of the patient's sleep, they are inexpensive, efficient and validated clinical tools. Even when objective data is possible to obtain through modern sensing solutions, this does not help understand the subjective experience and complaints of people. For this reasons, subjective report of sleep quality is still indispensable.

Some health clinics treating patients diagnosed with sleep disorders use sleep diaries written by them from scratch. However, this makes it difficult to compare patient data and related practices. For this reason an expert panel of twenty-five attendees of Pittsburgh Assessment Conference have attempted to align and standardize these sleep diaries and proposed the Consensus Sleep Diary (Carney, 2012). The Consensus Sleep Diary is a table of nine text items which patients have to record daily over a period of time. The items that the diary measures are the following:

1. What time did you get into bed?
2. What time did you try to go to sleep?
3. How long did it take you to fall asleep?
4. How many times did you wake up, not counting your final awakening?
5. In total, how long did these awakenings last?
6. What time was your final awakening?
7. What time did you get out of bed for the day?
8. How would you rate the quality of your sleep?
9. Comments.

(Carney, 2012)

The items are presented in a tabular format, requiring the participant to record times, (items 1-7), using a rating scale (item 8) and inserting free text (item 9). These information entry tasks can be tedious which can only diminish adherence. For this reason, it be-

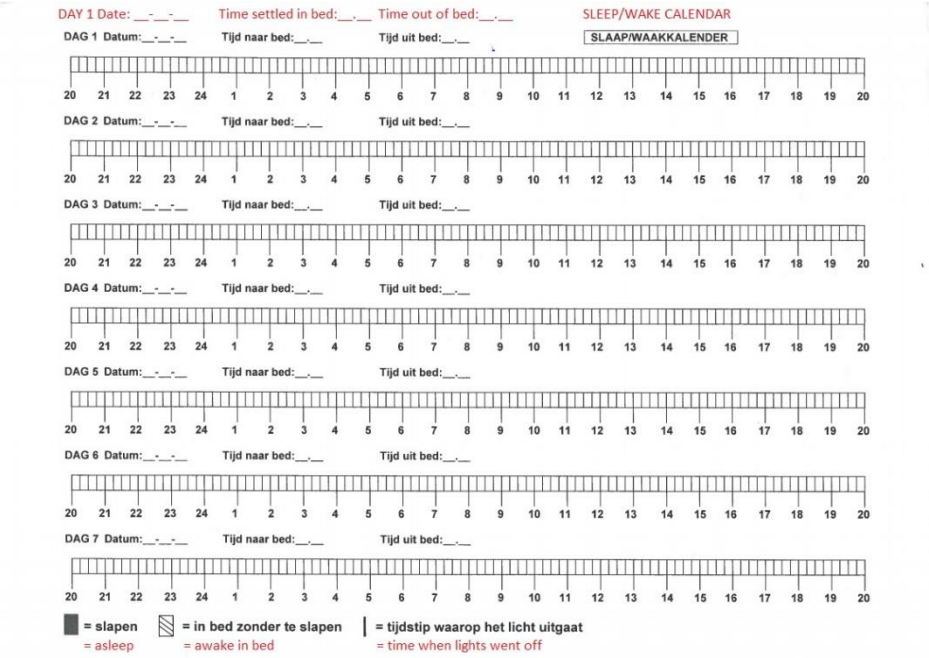

Figure 1: Paper-based sleep diary used at Kempenhaeghe Center for Sleep Medicine. The text in black is in Dutch language and the text in red represent English translations.

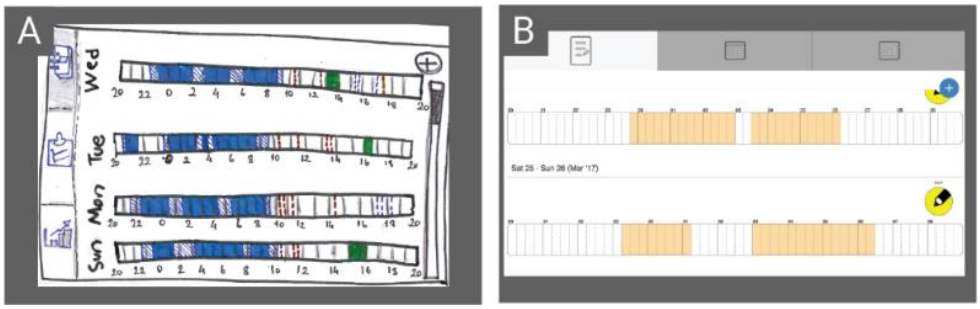

Figure 2: Initial sketch of the sleep diary concept and a screenshot from the first version of sleep diary tool.

comes interesting to use graphical formats for entering the same which trade off the precision of entry (e.g., entering the exact minute of going to bed), with an ease of use and an intuitive presentation of the information. Such an approach has been developed and is used at Kempenhaeghe Center for Sleep Medicine as seen in Figure 1. This sleep diary uses a graphical timeline for each day on which the patient has to enter the data about the previous night's sleep. One A4 single-sided page spans seven days, which makes it easy for the somnologist to get an overview and identify the sleep patterns of the patient over a period of one week. At least two weeks of data are required from the patient, but it can also be that patients will deliver more weeks of data due to waiting times before the patient is scheduled for the visit. The patient can mark on the timeline the following information:

1. Date.
2. Time settled in bed.
3. Time patient got out of bed.
4. Sleep (Marked with a full cross-hatching on the paper).
5. Awake in bed (marked with half cross-hatching on the paper).
6. Time light goes off (marked with a vertical bar).
7. Comments (optional on the back side of the diary).

The patient receives instructions on how to fill in the sleep diary together with the diary pages. We note that except for item 8 all items from the consensus sleep diary are also encountered in the sleep diary in use at Kempenhaeghe. While the graphical format makes entering information and gaining an overview easier, it still suffers from the limitations of paper noted in the introduction. Digital diaries overcome these limitations, and while some work has been done in this direction (Blake, 2010), none of the digital diaries to our knowledge feature a graphical input that would facilitate an easier and more pleasant experience for filling in such a diary. For this reasons, a digital version of this diary has been designed and evaluated.

3 THE HYPNOS DIGITAL SLEEP DIARY

Hypnos was developed in an effort to digitize and improve the sleep diary in use at Kempenhaeghe described above. Advantages of digital data collecting tools are numerous. The interface emphasizes the visual representation of data to enable easy logging of data and build on the human innate ability to perceive complex visual scenes fast (Thorpe, 1996). Hypnos was developed using the Ionic Framework, a mobile application development framework that allows targeting multiple platforms with one code base. Ionic, based on Apache Cordova, allows the production of hybrid web apps that target both Android and iOS platforms from a single codebase. Even more, the app can run as a web application as well, given that the languages used by the framework are HTML, CSS and JavaScript. Digitizing the diary can help ensure the integrity of the self-reported information, which is essential for a precise diagnosis and treatment. Possible input errors such as filling in an amount of sleep that exceed the amount of time spent in bed are possible with the traditional pen and paper sleep diaries. For this the digitized interface of Hypnos makes the time slot obvious for a user, thus making this type of error not possible. Following the design of the graphical paper diary, the timeline is divided into fifteen minutes time slots to enhance ease of entering information – note that more precision in the timeline (e.g. 1 minute time slots) would not necessarily correspond with how well patients can recall the sleep times.

The user interface was designed in an iterative fashion. Paper mock-ups like those shown in Figure 2 were discussed with five behavioral therapists specialized in the treatment of sleep-related disorders.

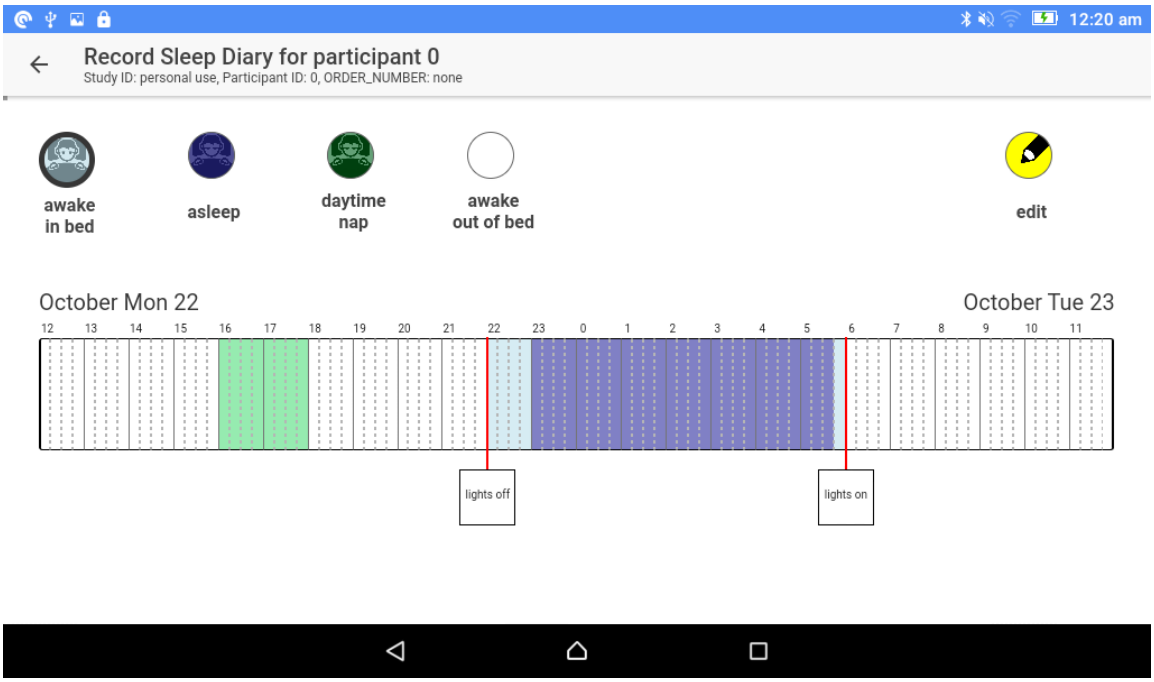

Figure 3: Final user interface for Hypnos application.

The design received positive reactions, e.g., a behavioral therapist found the way of registration easy to use and natural and commented: “It is like you are colouring it yourself.”

In the first designs, sleep parameters (e.g. sleep efficiency, wake after sleep onset) were not displayed to users. Following expert feedback it was decided to focus on the interface on sleep logging to make the tool generic and simple to use. Further additions were made to align the tool with clinical practice: naptimes are added as a separate entry, and finally, lights on and off feature are added.

The functionality of Hypnos is divided into two main features: “Record Data” and “View Data”. These two options are displayed as the start point in the application. “Record Data” will open an empty timeline. Here, users are allowed to input the following sleep states: “awake in bed”, “asleep”, “daytime nap”, “awake out of bed”. Additionally “lights off” and “lights on” timeline markers have to be placed at the corresponding time on the timeline. Users have to select one of the four states and select timeslots with a swipe gesture on the desired time slots thus making it easy and interactive to fill in the diary by colouring time slots through simple gestures. Awake out of bed, a sleep-related state itself can be perceived as an erase action on the timeline. After participants finished inserting data on the timeline, they can save the data by pressing the “done editing” button. If a user realizes that data has not been inserted correctly, they can re-edit data by pressing the edit button. Sleep data can be inserted only for the previous day, thus ensuring quality of the self-reported subjective sleep data. Users can go back to the start screen by pressing the go back arrow located in the top-left side of the screen. If users press the “View Data” button a new screen will open displaying a grid of sleep diary entries. The users can select a particular entry, by tapping on it. A new screen will open displaying the sleep timeline for the particular day as well as the following sleep parameters: total time asleep, total time awake in bed, total time fully awake, total time in bed, total time napping, wake after sleep onset, sleep efficiency and sleep latency.

3.1 Application Workflow

The application workflow is depicted in Figure 4. Hypnos has six different screens: Splash screen, Choose Action, Record Data, View Data, Saved Data and View Sleep Diary Entry. Each screen is briefly described below:

1. Splash Screen is displaying a detail of the painting “Starry Night” by Dutch painter Vincent Van Gogh while the application is loading.
2. Choose Action screen displays two options the user can choose from: Record Data or View Data.
3. Record Data screen shows an empty twenty-four hour timeline, spanning over two days, with the mid-

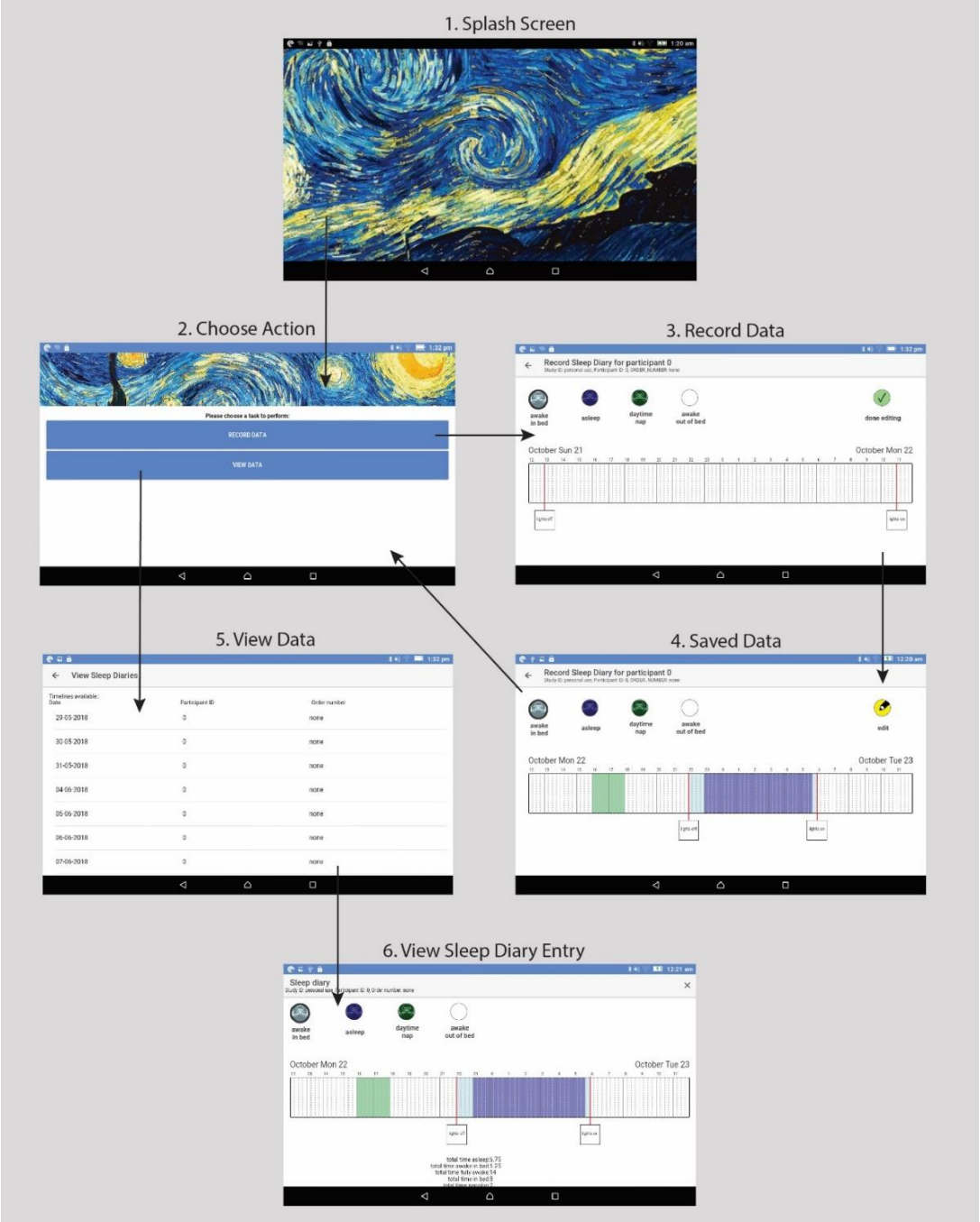

Figure 4: Application workflow.

night located in the middle. The reason for this is to facilitate inserting of sleep data over one timeline. If the timeline would be displayed between 00:00 – 23:59 most users will have to input sleep data over two separate timelines.

4. Saved Data is shown after the user has finished inserting data, and has saved data by pressing "done editing" button.

5. View Data screen displays a grid of sleep diary entries. The user can select one of the entries.

6. View Sleep Diary Entry shows recorded data of a certain day, together with the associated sleep parameters (sleep efficiency, sleep latency, total time asleep, etc.).

4 USABILITY STUDY AND USER EXPERIENCE STUDY

A field trial of Hypnos was conducted with the aim to provide a summative evaluation of its usability (ISO, 2018) and of the emerging user experience (Law, 2012). Usability in this context is vital for ensuring the quality of the collected data, reduce the workload of the users and thus enhance adherence. Whereas usability captures aspects such as ease of learning and ease of use, we are also interested in a more holistic understanding of all aspects of the end-user's interaction with the product, which is captured by the concept of user experience. As a secondary (formative) objective we set out to identify opportunities for improving Hypnos.

4.1 Research Plan

The research took place in different stages. For a visual description of the different stages please refer to Figure 5. The first stage of the study required that participants used the application and got accustomed with Hypnos by following a set of tasks. Participants were required to accomplish the tasks in laboratory setting with think-aloud method (Nielsen, 1993) and researchers observed participants' interactions with Hypnos, which further allowed to gain qualitative data regarding usability issues in Hypnos application. The task list the participants had to complete was as follows:

1. Locate the app icon and open the app.
2. Open "Record Data" functionality in the app.
3. Input when lights went off in their bedroom the previous night.
4. Input when lights went on in their bedroom the previous night.
5. Fill in nap times of the previous day.
6. Fill in the times he/she was asleep the previous day.
7. Fill in the times he/she was awake in bed the previous day.
8. Fill in the times he/she was awake out of bed the previous day.
9. Save the data in the diary.
10. View saved data.

After completing the predefined task list participants were required to complete the System Usability Scale questionnaire (Brooke, 1996) and Insomnia Severity Index questionnaire (Morin, 2011). Afterwards participants were given a Lenovo Tab3 7 Essential tablet, with a screen resolution of 1024X600 and 7" screen size, or a Samsung S8 smartphone with a screen resolution of 2960 X 1440 pixels and 5.8" screen size to take at home with Hypnos application installed. In total nine tablets and nine smartphones were distributed. It was required that they fill in a sleep diary daily for ten days, after which the second assessment took place. The next stages took part during the post-study session. During this session, participants handed in the devices to researchers and answered questions in an exit interview. The interview was semi-structured and audio recorded. Researchers took notes during the interview and referred back to the audio recording when needed. The information from the interview was grouped in items participants liked about the sleep diary, items participants did not like about the sleep diary, and recommendations for improvements that participants made.

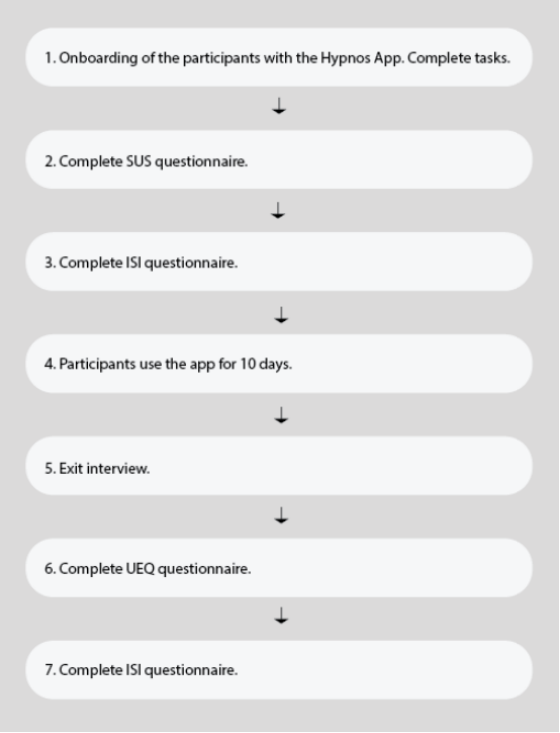

Figure 5: Research plan divided in the different stages.

After the interview participants filled in the User Experience Questionnaire (Laugwitz, 2008) and the Insomnia Severity Index questionnaire for a second time.

4.2 Measures

Three questionnaires were used as means of conductive quantitative research, and observation of user interaction and an exit interview were the means of conductive qualitative research.

4.2.1 Insomnia Severity Index (ISI)

The Insomnia Severity Index is a brief screening assessment tool designed to evaluate insomnia through seven Likert style rating scales with scores ranging from zero to four. The scores are added up and interpreted as follows:

- 0–7 = No clinically significant insomnia
- 8–14 = Subthreshold insomnia
- 15–21 = Clinical insomnia (moderate severity)
- 22–28 = Clinical insomnia (severe)

The ISI is one of the most widely used assessment instrument in clinical and observational studies of insomnia. It was adopted in order to track self-perceived sleep problems before and after using the sleep diary and to verify the stratification of participants sleep issues - as it was not intended to include only problem sleepers in the study.

4.2.2 System Usability Scale (SUS)

Usability was evaluated with SUS, a short and widely used questionnaire which consists in ten rating scales ranging from 0 to 10. By adding up ratings an overall usability score from 0 to 100 can be derived. (Brooke 1996). Given the wide use of SUS it is possible to compare the ratings for any particular system to data collected from 446 studies with over 5000 individual SUS responses, the overall mean SUS score for this data set was 68 with a standard deviation of 12.5. (Sauro, 2012).

4.2.3 User Experience Questionnaire (UEQ)

The main goal of the UEQ is to deliver a fast measurement considering aspects of pragmatic and hedonic quality.
The User Experience Questionnaire is a 26-item questionnaire used for measuring the subjective perceived user experience of artefacts. The reliability of UEQ scale is quite high with Cronbach-Alpha coefficient typically greater than 0.7 (Santoso, 2016). The 26 items measure user experience aspects grouped in six subscales:

- *Attractiveness*: Overall impression of the product. Do users like or dislike it?
- *Perspicuity*: Is it easy to get familiar with the product and to learn how to use it?
- *Efficiency*: Can users solve their tasks without unnecessary effort? Does it react fast?
- *Dependability*: Does the user feel in control of the interaction? Is it secure and predictable?
- *Stimulation*: Is it exciting and motivating to use the product? Is it fun to use?
- *Novelty*: Is the design of the product creative? Does it catch the interest of the users?

4.3 Participants

For the evaluation of Hypnos 18 participants (5 male and 13 female) were recruited and invited to participate in the study with a mean age of 29.4 years (SD = 3.39). Recruitment took place at the department of Industrial Design of Eindhoven University of Technology. Researchers invited master and doctoral students to take part in the evaluation study. Each participant was involved in the study for ten days: a forty-five minutes pre-trial session, ten days trial period of Hypnos and one post trial session of forty-five minutes. Participants gave informed consent and were rewarded after the study with a ten Euro voucher at an online book store.

5 RESULTS

5.1 Results of the Quantitative Assessment

5.1.1 Results from the System Usability Scale (SUS)

Hypnos received a mean usability score of 74.58 (SD=9.36). Scores were very similar for participants using phones (M=74.4 , SD = 8.64) and participants using tablets (M = 74.72, SD = 10.56).
A One-Sample T Test showed that participants evaluated the usability with the SUS questionnaire significantly higher than the population average of 68, $t(17) = 2.98$, $p = .008$. By referring to the conversion table of SUS scores to percentile ranks that can be found in (Sauro, 2012), it can be deducted that Hypnos can be considered more usable than 70% of the products in the Sauro database and less usable than 30%.

5.1.2 Results from the User Experience Questionnaire (UEQ)

All eighteen participants completed the UEQ questionnaire after the experiment period of ten days. The results of the UEQ questionnaire are displayed per scale in Figure 6 (numeric) and Figure 7 (graphical). The UEQ does not produce an overall score. Values between -0.8 and +0.8 represent a neu-

UEQ Scales (Mean and Variance)		
Attractiveness	0.898	0.60
Perspicuity	2.042	0.58
Efficiency	1.556	0.42
Dependability	1.431	0.23
Stimulation	0.653	0.53
Novelty	0.028	0.59

Figure 6: Results of UEQ (numeric).

tral evaluation of the corresponding sub-scale, values > +0.8 represent a positive evaluation and values < -0.8 represent a negative evaluation. The range varies between -3 (horribly bad) to +3 (extremely good). It is extremely unlikely to obtain values over +2 or lower than -2, thus even a quite good value of +1.5 looks visually not as positive as it is on a scale from -3, +3 (Santoso, 2016).

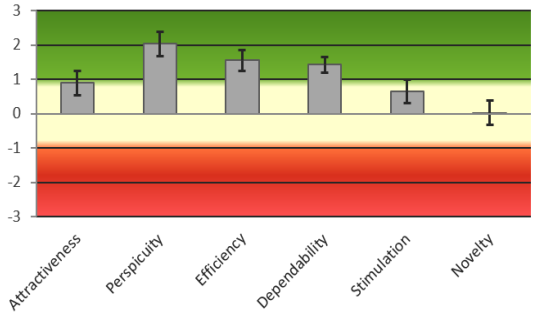

Figure 7: Results of UEQ (graphical).

By looking at the results, it can be observed that only the hedonic dimensions show neutral values: Stimulation (M=0.65, SD=0.72) and Novelty (M=0.02, SD=0.76). This was expected as the purpose of Hypnos was to offer a simple and practical digitized version of a sleep diary, that could be used in clinical context rather than an engaging user experience. Not to be ignored, hedonic traits need further investigation and research to provide input for further iterations of Hypnos that will finally fulfil these characteristics as well. Perspicuity, Efficiency and Dependability mean values represent a positive evaluation, while Attractiveness is borderline and can still be improved in future iterations.

5.1.3 Results from the Insomnia Severity Index (ISI)

Only 17 participants were included in the test, as one participant did not fill in one of the two ISI questionnaires. Descriptive statistics show that for the pre-experiment ISI questionnaire trial (M=8.58, SD=6.08), and for the post-experiment ISI questionnaire trial (M=9.17, SD=6.51). A Wilcoxon Signed-Ranks Test was carried out using SPSS on the pre and post study ISI results and indicated no statistically significant results with Z=.492, p<.623, therefore no conclusions can be drawn.

5.2 Results of the Qualitative Assessment

5.2.1 Observations during Onboarding

Except two participants, everyone involved in the study completed the ten tasks described in 4.1 with minimal help from the researchers (the sleep diary did not have a user manual at the time of the evaluation therefore a researcher was available for help in case participants would get stuck). One of the most commonly encountered issue during the onboarding of the application concerned erasing data in the sleep diary. Because there was no erase or delete icon in the application, and because the awake out of bed icon is completely white, and does not refer to a delete or erase action, participants found it difficult to map this icon to the action of erasing. “Lights on” and “lights off” markers on the timeline of the application were also not clear for participants and required further explanations on how to set markers in relation to their sleep experience.

5.2.2 Exit Interview Results

The exit interview had the main purpose of collecting qualitative data.
The data gathered during the interview was grouped in three categories: Pleasant, Unpleasant and Improvements. Below we present some of the pleasant, unpleasant and improvements points collected through qualitative research.

- **Pleasant**

One of the most encountered feature participants mentioned as pleasant was that the simplicity of the app. After the onboarding the functionality was clear for the participants and they did not encounter problems while filling in data at home in the sleep diary. Another encountered item mentioned by participants was that they were more aware of their sleep routines and that they could plan their sleep better because of this. One of the participants also mentioned that filling in the diary is quite fun and practical, and that after a certain period of time it becomes a habit: “It’s quite practical actually, and because I record all my data every single day, it made me have this behaviour to be more aware of how my sleep is in the recent ten days, so I have an overview

of my sleep status. And it is quite fun to use". Also, the simplicity in interaction to fill in the diary was mentioned by participants.

- **Unpleasant**

During the exit interview most of the participants complained about the size of the slots in the timeline they had to fill in. For example, one participant mentioned he felt he had a fat finger, because he could not precisely select the correct time slot without zooming: "…like I said, the feeling of having a fat finger that encroaches on other things, that was the only real frustration that I had with it...". Other participants complained that they felt under pressure to fill in the sleep diary "…because I must record, so it is a pressure on me…" and that it is hard to remember to fill in the sleep diary on time.

- **Improvements**

Participants suggested that offering a better overview of their data that would include meaningful visualisations and patterns would be desirable. Participants also mentioned that they would like to be able to add comments on the data they filled in, e.g., to note reasons on why they woke up at night: "…maybe when you wake up at night, that you can indicate why…", or what was the reason for which they needed to take a nap in the afternoon. Some participants also noted that zooming and scrolling on the timeline was difficult. A few participants mentioned the wish of being able to see more diaries on one page. This way a pattern of their sleep behaviour could be better observed. Other improvements suggested by participants are: reminders, recording mood of the day, recording objective data such as location of sleep, snooze events as well as self-reported information like the description of dreams.

6 CONCLUSIONS

Hypnos is a graphical digital diary that allows to report easily sleep data traditionally captured in paper diaries. Its design emphasizes simplicity and supports an overview of sleep data that can be useful to clinicians as well to researchers.

The results of the quantitative assessment were not unexpected. The usability of the app was evaluated positively. The user experience evaluation found positive scores with regards to pragmatic aspects of the user experience (perspicuity and usefulness), but showed that the device could be made more engaging and innovative. This enforces that the next steps needed to be taken in the following iterations of Hypnos should be in the Stimulation and Novelty dimensions defined by the UEQ questionnaire. The qualitative assessment results identified several usability and user experience issues that need more consideration. By addressing them, we can only expect that usability and user experience will improve.

For these reasons, Hypnos would need another iteration for addressing the identified issues, and conduct a final usability and user experience with both clinicians and patients before positioning it as a clinical tool.

In terms of study limitations, we are aware of the fact that the participants recruited were on average younger than our potential target population, highly educated and healthy. Being in a highly educated young age segment of the population, it is more likely that they are digital native, proficient with tablets and smartphones, and learn quicker than seniors.

Both clinical practice and research need such a tool for multiple reasons. It is clear that digital sleep diaries have advantages over traditional pen and paper diaries such as: data input validation, collecting quality data, higher adherence, safe storage and a better user experience. Both clinicians and patients would benefit of such advantages, with the end result of a better treatment. Researchers by potentially having access to big data collected through time can conduct higher quality research and process data easier. Therefore, based on this study, the authors propose to run another development iteration of Hypnos that will improve the usability and enhance user experience of the app which will further be tested and validated.

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