EVE: A Combined Physical-Digital Interface for Insomnia Sleep Diary

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Abstract. Insomnia is a medical condition with high prevalence and negative impact on quality of life. As a part of various therapies, sleep diaries are used as a tool for diagnosis and patient self-management. Traditional diaries are essentially paper forms, which are cumbersome, error-prone and time-consuming. Application (app) based diaries have been proposed, but they are screen based and have their disadvantages. We report on the design of EVE, an alternative type of sleep diary. The design is based on a combined physical-digital interface. Three prototypes have been built, and two of which (PINS and RING DIAL) have been tested in a preliminary user test. PINS came out on top in the subjective preference survey between two of the prototypes. Participants perceived both prototypes as enjoyable and easy ways to log essential sleep time. Our design suggests this combined interface has the potential to promote patients to provide reliable insomnia sleep diaries.

Keywords: Insomnia · Interface design · Interaction evaluation

1 Introduction

People spend a third of our life sleeping. Thus, sleep plays an important role in our life. However, a large population suffers from all kinds of sleep disorders, among which insomnia is one of the most prevalent sleep disorders. Insomnia characterized by troubles in falling asleep, staying asleep, waking up too early and feeling tired upon waking that results in a poor quality of the day through daytime sleepiness and a lack of energy. Insomnia affects in about 33–50% of the adult population of the United States making it a serious problem requiring effective treatment [1]. Insomnia is a disorder that is not only caused by medical problems, but it is related to subjective experiences of both the quality and quantity of sleep that causes the problem [2]. To obtain an overview of patients' condition, an assessment is important for the sleep clinician.

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Many different methods and tools have been developed for covering both subjective and objective insomnia assessment by researchers in different areas such as Sleep Diary for the subjective assessment and Polysomnography for the objective assessment [3]. As the primary subjective method, self-reporting normally could provide a fast estimation of sleep initiation and maintenance [4]. However, the result of self-reporting highly relies on the subjects' memory and cognition. Patients' are normally recommended to log their sleep data timely for obtaining the accurate assessment. The most of the research in insomnia self-reporting put effort on finding a reliable and valid index, such as Pittsburgh Sleep Quality Index.

This paper explores a new avenue of increasing the accuracy of the result by increased usability and enjoyability of the insomnia self-reporting instruments. The paper is organized as follow. In the section two, the paper summarizes the treatment and diagnosis method of insomnia and addresses the problems of the method. Then the paper perposes a new method in the section three. The preliminary user test design and data analysis are covered in the section four. The section five addresses the conclusion from the result and pictures the future study.

2 Treatment and Diagnosis of Insomnia

2.1 Sleep Diaries

Many people with insomnia overestimate their sleep disruption and underestimate their actual sleep time, a precise assessment is needed for the sleep clinician to estimate the severity of the problem, especially the night-to-night variability and the presence of sleep-influencing habits [5]. An essential component of insomnia assessment is, therefore, the sleep diary. A sleep diary is a record of sleep details filled in by a patient, usually over a period of two weeks or more. Sleep diaries are the standard in assessing insomnia to record sleep patterns, the variability of the nights, maladaptive habits, difficulties and overall sleep efficiency [6].

2.2 Current Sleep Diaries and Problems

Currently, most of the sleep diaries adopt a paper-and-pen approach to user input. Diaries consist of a wide range of questions regarding sleep time and other key factors. Patients complete a sleep diary by filling in answer to each question. For obtaining an accurate overview of the symptom, the diary needs to be completed timely (fill essential time right after wake up, etc.). Due to the large cognitive efforts that patients need for the data input, completing a paper-based sleep diary has been perceived as a demanding task by patients (results in an inaccurate data input). The conflict between the needs of accurate data for a better clinical diagnosis and the inaccurate data input makes the current sleep diaries have less reliable.

Several app-based sleep diaries, such as SLEEP TIME+ [7] and SLEEP GENIUS [8], have been developed. Apps benefit from the computing capability of smartphones, the enormous 3cloud storage space, and the Internet, and therefore are superior to paper-based sleep diary in many aspects. However, the disadvantages of app-based

sleep diaries are also obvious: several studies have been done on the negative impacts that in-bed mobile usage on our sleep quality [9, 10]. As a result, app-based sleep diary could lead insomnia patients into bad sleep hygiene.

Additionally, most of the app-based sleep diaries are developed with Graphic User Interface (GUI). Although the advantages are significant, the disadvantages of GUI have been addressed by many researchers [15, 16]. In the meantime, several HCI studies suggested that Tangible User Interface (TUI) is better than GUI in the aspects of usability and user experience. Benefit from the involved physical elements, users can perform the interaction faster [16], easier [15], satisfaction [17] and more nuanced in TUI compared to GUI.

3 Combined Physical-Digital Sleep Diary

For addressing the current diary's shortcomings and promoting patients logging properly, we did references study in the field of interaction design and design principle. We found certain studies made their contributions for reducing cognitive loads for the users and extending the usability of the products, such as Progressive Disclosure [13] and Mode-relevant Action-possibilities (MR APs) [14]. Progressive Disclosure is a design principle which emphasizes the leveled information and interaction disclosure. It offers an approach to help maintain the focus of users' attention, by disclosing the most wanted information to users when the users need and offering the interaction to users when necessary. Progressive Disclosure can help users dealing with massive information overload. Users can manage the complexity of feature-rich data with low cognitive workloads. It follows the typical ideology of 'moving from abstract to specific'.

Moreover, in MR APs approach, the mode of interaction has been discussed. It believes that the interaction should be relevant only offered when they are relevant for the mode-of-use. The form of the interface, the way of the interaction should be integrated with the function. The form has the meaning which can transfer to the interaction. And interaction is the carrier of the meaning of function. The right coupling of form, interaction and function promotes the usability of the design.

Inspired by these approaches, we refined the use cases of sleep diary and selected the users' essential sleep time input as the function for the further exploration. We wanted to explore the most appropriate interaction and form based on the given function. Following the notion of 'leveled disclosure', we decided upon an approach combining physical input with a digital component. The physical input (for logging essential sleep time) would serve as the first step, with a low threshold for the user to interact within a fast, tangible and enjoyable way. The digital component with Graphical User Interface would serve as a second step to collect additional detailed, sleep-related information and proceeds to send this data back to the sleep institute. We believed that through this approach we would be able to design a product that would stimulate continued, proper use through an inviting and pleasant interaction.

This approach led to our design concept of EVE, a new, subjective sleep diary which aims to contribute to the efficient and accurate treatment of insomnia patients.

4 EVE Sleep Diary 2.0

The sleep diary consists of two parts: A physical interface for simple essential time logging and a mobile app.

(1) *Physical interface*

For exploring the physical user interface, we proposed three interfaces with different interaction models: (1) PINS concept elaboration consists of 24 pins, which can be pressed and pulled. The pins stand, in zero position, a few centimeters (5 cm) up. Each pin visualizes half an hour. In order to indicate a specific time, the pin will need to be gently bent back or forward. The time will be visible on the display, which is located in the middle of the circle. When the patient wakes up and sits down on the edge of the bed, the circular product lights up. The pins are in the zero position. The patient records the sleep time by pushing the pins completely down. The awake time is recorded by keeping the pins in the current position. The product knows that this part consists of the awake time. (2) RING DIAL concept elaboration consists of a rotating ring on the top of the product, with a hole for the finger on one side of the upper area. The ring can be rotated in order to record the sleep time and awake time by placing the finger in this hole. When the user presses harder in the hole, the sleep time will be recorded. During the rotation of the ring, the time will be visible on display at the center of this ring. (3) FLEXIBLE SURFACE concept elaboration consists of a flexible ring on the upper surface of the product. This flexible circle can be pressed, after which it bent out of shape. The surface that is pushed lights up. It does not consist of moving pins, but from a solid surface which can be formed. Figure 1 shows the prototypes that we implemented in the followed iterations.

Fig. 1. Cardboard prototypes of three physical interfaces.

In addition, sensors are embedded in the physical interface. By placing the physical interface on the bed, user's in-bed time is measured. The in-bed time will be visualized by LEDs on the physical interface as a reference when the user is logging the essential sleep time input.

(2) *Mobile application*

All three of the concepts are synchronized with a mobile app. This mobile app shows a similar interaction design, the circular timeline. Bringing the interface design

of the physical product closer to the interface design of the digital product will create a better understanding of this sleep diary. This strengthens the unity between the physical and digital.

The mobile app supports the physical product. The main input is entered from the physical product. The patient can view the completed diary of the last night on the mobile app. The additional information and data can be filled in on the mobile app. Additional information may consist of the consumption of caffeine, alcohol or medicines and doing sports. Figure 2 shows the main screens of the mobile app.

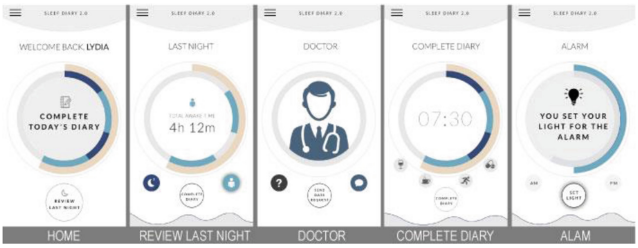

Fig. 2. Main screens of the mobile app.

5 Preliminary User Test

A preliminary user test was conducted for evaluating the proposed prototypes. The Flexible surface was withdrawn because of the negative opinions by the several participants. The following hypotheses were tested:

H1. The proposed physical user interfaces provide a low effort solution for users to input the essential sleep time.
H2. Users enjoy the experience of logging their essential sleep time with the proposed physical user interface.

5.1 Method

With this the user test, we intend to (1) test the proposed hypotheses. (2) Besides validating the current concepts, and find out the concept which offers the best usability, we would like to (3) gain additional insights in the way of time perception by observation and interview. A within-subject design was applied in this test which includes questionnaires, interviews and open questions.

The user test consisted of three sessions. Firstly, participants completed the tasks with each prototype without any hint from the experiment conductor. The tasks were designed as certain sleep diary filling and data modification events. In the second session, participants completed the similar task as the first session, with hints from the experimenter. In the first two sessions, the order was balanced between participants. In the third session, participants filled a nine items questionnaire (Table 1). For avoiding the neutral results, participants were asked to fill in six point Likert scale answers. The questionnaire consisted of two dimensions: usability and enjoyable using. Eight

usability questions which adapted from Lund's USE Questionnaire [11] and one question we designed for the enjoyability was included in the questionnaire. At the end of the third session, a subjective Preference Survey was filled where the preference of PINS and RING DIAL were ranked and, moreover, the 'why' of the preference could be explained as an open question and 'other remarks' could be given.

Table 1. Items of questionnaire

Questions
1. I understood how the device/interaction worked
2. I was able to fill in my sleep time
3. I was able to fill in the time I was a wake
4. I was able to tweak/correct my sleep time
5. The product worked as I expected it to
6. It did not take much effort to complete the task/fill in the diary
7. I found the overall interaction quick
8. It felt 'right' to fill in the diary in this way
9. I enjoyed filling in the diary/using this concept

5.2 Participants

Eleven participants (5 female, ages from 18 to 91) were recruited. Three participants have a design background. The test was focused primarily towards validating the proposed prototypes. Therefore, it is not necessary to test on insomnia patients in this stage.

5.3 Material

Cardboard prototypes have been made for exploring the interactions (Fig. 1).

5.4 Questionnaire Result

A paired t-test was used to analyze whether there were any significant differences in the two dimensions between the PINS and the RING DIAL.

The result of usability of both the PINS and the RING DIAL were not high (PINS: $M = 3.80$, $SD = 0.33$; RING DIAL: $M = 3.48$, $SD = 0.58$). No significant difference had been found between two prototypes ($p = 0.12$).

On the 'enjoyable using' side, both prototypes scored similar (PINS: $M = 4.09$, $SD = 0.70$; RING DIAL: $M = 4.18$, $SD = 0.75$), higher than the median score ($M > 2.5$, 5 = strongly agree). However, there was no significant difference in the enjoyable using between two prototypes.

5.5 Subjective Preference Survey Results

We summed the total score of the Preference Survey for each prototype to find out the most preferred prototype. As a result, PINS scored 7, superior to RING DIAL (score = 4).

To identify the prevalent concepts of each prototype, we coded the comments which we collected from the open talk after the first session and the text that participants wrote in the subjective preference survey. We classified the results into 11 concepts (6 positive and 5 negative concepts) and calculated the frequency of each concept. The concepts frequency is shown in Table 2.

Table 2. Concept frequency of prototypes as found in the 'why' and 'other remarks' questions

	Concept	Frequency	
		PINS	RING DIAL
Positive comments	Easy to fill in (EF)	3	3
	Clear concept (CC)	3	0
	Fast to operate (FO)	0	2
	Fun to use (FU)	1	1
	User-friendly (UF)	0	2
	Good looking (GL)	0	1
Negative comments	Unclear interaction (UI)	3	2
	Practical limitation (PL)	3	1
	Unclear feedback (UFB)	0	2
	Efforts needed (EN)	1	0
	Difficult to fill in (DF)	0	1

In general, the most prominent concept for both concepts was 'easy to fill in' (PINS: fEF = 3; RING DIAL: fEF = 3). The most frequently mentioned concept in negative comments was 'unclear interaction' (PINS: fUI = 3; RING DIAL: fUI = 2).

Some concepts showed high frequency in the comment of one prototype, but can't be found in the comments of the other. For instance, concept 'clear concept' had been mentioned three times in the comments of PINS, but never in RING DIAL's comments. As a result, the interaction mechanism of PINS was clear and easy to understand, But PINS had more practical limitation than RING DIAL (PINS: fPL = 3; RING DIAL: fPL = 1). On the other hand, RING DIAL was superior in the aspects of 'user-friendly', and 'fast data input' compare with PINS (PINS: fUF = 0, fFO = 0; RING DIAL: fUF = 2, fFO = 2). However, the critical defect of RING DIAL was the concept 'unclear feedback' (PINS: fUFB = 0; RING DIAL: fUFB = 2). The frequency of four concepts (GL, EN, FU and DF) had insignificant differences between two prototypes.

5.6 Discussion

The result of the usability questionnaire suggested that both PINS and RING DIAL were not high. The similar result also can be found in participants' comments on the

open questions 'why' and 'other remarks'. Several mentioned that both prototypes had certain interactions were defined unclearly. Two possible explanations regarded to the test setup and test material were proposed: (1) All the participants in this test had little experience with sleep diary and essential time logging. For the participants with the experience of using sleep diary, we assume the usability score of both prototypes would be higher, and the difference in the usability of both prototypes would be obvious. (2) Both prototypes were made by cardboard without digital components. Certain interactions relayed on the participants' imagination which needs a high cognitive load. Finally, it could result in a low usability score.

Regarding to enjoyability, both prototypes were rated higher than the median score ($M > 2.5$, 5 = strongly agree), with a non-significant difference, by the participants. Our observation and participants' comments in the third session also found that participants enjoy the experience during interacting with both proposed prototypes (H2).

The analysis of the subjective preference survey revealed the different pros and cons between two prototypes. Some differences were significant. Associated the result of preference ranking and the result of concept frequency statistic, we found that the concepts weight differently on participants' preference. As the most welcome prototype, PINS had only one higher frequency concept, however, RING DIAL had three. In addition, participants had more complaints on PINS than RING DIAL. This phenomenon suggests that users intend to prefer the interface which delivers clear message on 'how does it works' to which makes its user more efficient. On the other hand, a useful feedback could earn preference from its users. Furthermore, the concepts frequency rating indicated that 'Easy to fill in' was the most prominent feature of two prototypes. More than one-third of the participants perceived the proposed physical interfaces as the easy ways for the essential data input. As a result, both proposed prototypes were the solutions for the effortless essential sleep time input (H1).

We could conclude that the proposed hypotheses were partially supported by the result: 'the proposed physical user interfaces provide a low effort solution for users to input the essential sleep time' (H1) and 'Users enjoy the experience of logging their essential sleep time with the proposed physical user interface' (H2).

6 Conclusion

As a large scale task, complete a sleep diary is a demanding mission for the insomnia patients. In practice, the questions of an insomnia sleep diary, such as the Consensus Sleep Diary [12], are highly context related. Patients should not be exposed to the overwhelming data input tasks. Separating the large scale tasks into smaller scale tasks based on context, and ramping up the patients from general, easy to detail, complex data input is one of the methods to ease the sleep diary logging. A progressive data input approach was adopted in our design. Patients input simple data with the simple physical interface and input complex data with the powerful graphical user interface. The result was promising. Our proposed prototypes had been perceived as easy and fun ways for logging essential time by the participants.

The user test is preliminary. There were defects in many aspects. A proper user test is needed with polished working prototypes which are shown in Fig. 3. Furthermore, a

learning session should be conducted before the lab study, for letting the participants obtain some experience with the sleep diary. A more validated user experience questionnaire will be applied for testing the user experience in next test.

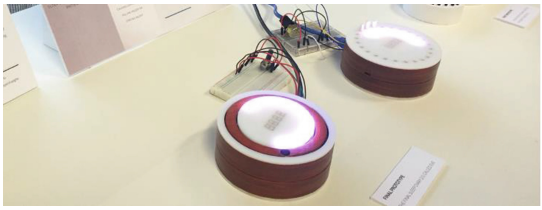

Fig. 3. The working prototypes.

In the follow-up research, the GUI version of the selected prototype will be implemented. And a study will carry out for comparing the usability and enjoyability between the selected prototype and its GUI version for addressing the cons and pros of both GUI version application and the combined physical-digital version application.

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References

1. Anocli-Israel, S., Roth, T.: Characteristics of insomnia in the United States: results of the 1991 National Sleep Foundation Survey. I. Sleep **22**, S347–S353 (1999)
2. Carney, C.E., Posner, D.: Cognitive Behavior Therapy for Insomnia in Those with Depression: A Guide for Clinicians. Routledge, London
3. Petit, L., et al.: Non-pharmacological management of primary and secondary insomnia among older people: review of assessment tools and treatments. Age and Ageing **32**(1), 19–25 (2003)
4. Floyd, J.A., et al.: Age-related changes in initiation and maintenance of sleep: a meta-analysis. Res. Nursing Health **23**(2), 106–117 (2000)
5. Saddichha, Sahoo: Diagnosis and treatment of chronic insomnia. Ann. Indian Acad. Neurol. **13**(2), 94 (2010)
6. White, A.G., Buboltz, W., Igou, F.: Mobile phone use and sleep quality and length in college students. Int. J. Human. Social Sci. **1**(18), 51–58 (2011)
7. Sleep Time+: 2014. http://www.azumio.com/s/sleeptime/index.html/. Accessed: 12 Oct 2016
8. Sleep Genius: 2015. http://sleepgenius.com/. Accessed: 12 Oct 2016
9. Cain, N., Gradisar, M.: Electronic media use and sleep in school-aged children and adolfescents: a review. Sleep Med. **11**(8), 735–742 (2010)
10. Hale, L., Guan, S.: Screen time and sleep among school-aged children and adolescents: a systematic literature review. Sleep Med. Rev. **21**, 50–58 (2015)
11. Lund, A.M.: Measuring usability with the USE Questionnaire 12 (2001)
12. Carney, C.E., et al.: The consensus sleep diary: standardizing prospective sleep self-monitoring. Sleep **35**(2), 287–302 (2012)

13. Brown, C.M.: Human-Computer Interface Design Guidelines. Intellect Books, Chicago (1998)
14. Frens, J.W.J.: Designing for rich interaction: integrating form, interaction, and function. Dissertation, Technische Universiteit Eindhoven (2006)
15. Fitzmaurice, G.W., Buxton, W.: An empirical evaluation of graspable user interfaces: towards specialized, space-multiplexed input. In: Proceedings of the ACM SIGCHI Conference on Human factors in computing systems. ACM (1997)
16. Klemmer, S.R., Hartmann, B., Takayama, L.: How bodies matter: five themes for interaction design. In: Proceedings of the 6th conference on Designing Interactive systems. ACM (2006)
17. Jacob, R.J.K., et al.: A tangible interface for organizing information using a grid. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM (2002)