Master Thesis

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Habstack

Analysing and Fostering Better Sleep Hygiene Routines using a Smartphone Application

Michael Ziörjen

of Aarau, Switzerland (15-716-954)

supervised by

Prof. Dr. Thomas Fritz
Anastasia Ruvimova
Kevin Chow

University of Zurich[UZH]

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Author: Michael Ziörjen, michael.zioerjen@uzh.ch

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Human Aspects of Software Engineering Lab
Department of Informatics, University of Zurich

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Abstract

This thesis explores the integration of habit formation techniques into a smartphone application to promote better sleep hygiene. Based on a literature review, the "Habstack" app was developed, incorporating habit-stacking, implementation intention rehearsal, and habit-tracking to support behaviour change. A two-week user study with 14 participants was conducted to test the feasibility of the approach and to evaluate the app's impact. A quantitative analysis of the usage data captured in the app and a qualitative analysis of interviews conducted at the end of the study was performed. The results suggest that the app was helpful and supported participants' in adopting the new sleep hygiene behaviours. To improve the effectiveness of the method, apps should provide a list of common existing habits, promote matching contexts for the habit-stacks, encourage placement of additional cues, and design reminders carefully to avoid users forming a dependency. These findings are discussed to complement existing design recommendations and to identify areas for future work. The findings provide preliminary evidence for the potential of habit formation techniques in promoting behaviour change in sleep hygiene but more work is needed to assess the long-term impact. The underlying approach and design recommendations provided could be applied to other domains and guide the development of future digital health interventions.

Zusammenfassung

Diese Arbeit untersucht, wie gewohnheitsbildende Techniken in eine Smartphone App integriert werden können, um bessere Schlafgewohnheiten zu unterstützen. Basierend auf einer Literaturrecherche wurde die "Habstack" App entwickelt, welche die "Habit-Stacking" Technik, das Üben von "Implementation Intentions" und das Überwachen des Fortschritts integriert. Um die Machbarkeit des Vorgehens zu testen und den Einfluss auf die Schlafroutine zu untersuchen, wurde eine zweiwöchige Nutzerstudie mit 14 Teilnehmern durchgeführt. Eine quantitative Analyse der in der App gesammelten Nutzerdaten und eine qualitative Analyse der Abschlussinterviews in der Studie wurden durchgeführt. Die Resultate deuten darauf hin, dass die App hilfreich war und die Teilnehmer beim Umsetzen der neuen Schlafgewohnheiten unterstützt hat. Um die Effektivität des Ansatzes zu verbessern, sollten Apps eine Liste mit gängigen existierenden Habits zur Verfügung stellen, habit-stacks mit passendem Kontext empfehlen, die Verwendung von zusätzlichen Cues fördern und die Erinnerungen sorgfältig gestalten, damit Benutzer keine Abhängigkeit diesbezüglich bilden. Diese Ergebnisse werden diskutiert, um bestehende Design-Empfehlungen zu komplementieren und um zukünftige Forschungsbereiche zu identifizieren. Die Ergebnisse liefern erste Hinweise für das Potenzial von gewohnheitsbildenden Techniken zur Förderung von Verhaltensänderungen im Bereich der Schlafhygiene. Der zugrunde liegende Ansatz und die Design-Empfehlungen könnten auf andere Bereiche übertragen werden und als Grundlage für die Entwicklung künftiger digitaler Gesundheitsmassnahmen dienen.

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Chapter 1

Introduction

"We are what we repeatedly do.
Excellence, then, is not an act, but a habit."

Will Durant, 1926 [1]

An international survey estimates that 56% of the American population suffered from sleep problems over the previous year compared to 31% in Western Europe and 23% in Japan [2]. These numbers are in line with more recent findings in Switzerland [3]. Depending on the definition used for insomnia, it is estimated that between 9-15% of the general population suffers from symptoms of it that have daytime consequences [4]. Participants with sleeping problems reported that it impacts their daily functioning and consequently negatively affects both their personal and professional lives [2]. Furthermore, it has been demonstrated that poor sleep has detrimental health effects (e.g., by degrading the performance of the immune system [5]), negatively affects cognitive performance [6], worsens mood [7] and when sustained over longer periods of time increases the risk of mortality [8].

Sleep hygiene education has been identified as a key strategy for improving sleep in the general population [9]. *Sleep hygiene* is defined as a set of recommendations for behaviours and environmental factors to promote healthy sleep, and was originally developed to treat mild to moderate insomnia [10]. Using technology to educate people about sleep hygiene and to help them incorporate and sustain healthy sleep habits could thus be an effective solution to the growing public health concern of 1 in 3 people having sleep related issues. This is especially true as the use of technology in general, and smartphones in particular, has grown steadily to the point where they are now considered to be ubiquitous. Education in the form of sleep hygiene recommendations usually consist of a list of behaviours to avoid (e.g., avoiding caffeine, nicotine or alcohol), behaviours that can promote sleep (e.g., stress-managing strategies such as meditation) and advice related to the timing of sleep (e.g., having a consistent sleep schedule) [9]. What these recommendations have in common is that they require a change in behaviour, either by adding new behaviour, changing existing behaviour or avoiding existing behaviour. While there has been a wide range of smartphone applications developed to address sleep related health issues, most existing solutions only include information about sleep hygiene but fail to support and sustain the required behaviour change [11, 12].

Supporting health behaviour change using technology has been studied in various areas before (e.g., physical activity [13] or healthy dieting [14]). However, the research area is fragmented with a large number of different theories, approaches and techniques and there is a general lack of long-term evaluation of the effectiveness of the proposed solutions [15]. Most solutions make use of

reminders (e.g. by using push notifications) and tracking functionality to track the adherence to the behaviour change. In some cases, elements of gamification are included in which users receive some kind of virtual reward for altering their behaviour. However, one aspect remains commonly overlooked: habitual behaviour [15]. Since habitual behaviour or *habits* (i.e., actions that are performed automatically in response to a given cue [16]) can be a key driver for long-term behaviour change, incorporating them into digital health interventions has the potential to increase their impact. In the context of health in general and sleep hygiene in particular, habits play an important dual role. Existing behaviour that negatively affects sleep can be habitual and thus difficult to change. And new behaviours need to become habitual to have a sustainable long-term impact on sleep. Unfortunately, most existing solutions aimed at changing health related behaviour do not yet address the habitual nature of these behaviours [15] and neither do solutions targeting sleep issues [11, 12]. One reason for the failure of existing solutions to address habitual behaviour is that the underlying theories of behaviour change and related strategies fail to consider the role of habits [15].

To address these limitations, this thesis aims to explore how strategies specifically targeted at habit formation can be incorporated into a smartphone application to foster better sleep hygiene. The three habit formation techniques examined are *habit-stacking* (i.e., combining an existing habit with a new behaviour), *implementation intentions* (i.e., formulating and rehearsing a sentence that identifies the situation to perform the new behaviour) and *habit-tracking* (i.e., tracking and reflecting about the progress with the new behaviour). A smartphone app was built that incorporates all three techniques to answer the following three research questions:

> **RQ1:** How can a smartphone application be designed to support habit-stacking?

> **RQ2:** How can implementation intention rehearsal support the process of habit-stacking?

> **RQ3:** What is the impact of the smartphone application on supporting users in building better sleep routines?

This thesis is structured as follows: First, relevant concepts and habit formation techniques are described and the relationship between smartphone usage and sleep is examined (Section 2.1). This is followed by an overview of existing work in the domain of sleep hygiene interventions and habit formation apps to identify limitations and derive design recommendations (Section 2.2). The next chapter describes the design and implementation of a smartphone app and how it was evaluated during a user study (Chapter 3). Subsequently, the findings are presented (Chapter 4) based on an analysis of the captured usage data and semi-structured interviews conducted during the study. Finally, these findings are discussed to complement existing design recommendations and to identify limitations and areas for future work (Chapter 5).

In summary, this thesis makes the following contributions:

1. It synthesises the results of prior work to identify design recommendations for smartphone apps that use habit formation techniques to support behaviour change.
2. It provides the design and implementation of a smartphone app that incorporates the design recommendations in the domain of sleep hygiene.
3. It presents findings from an empirical user study (n = 14) that demonstrated the impact of the app and identifies additional factors to complement the design recommendations from the existing literature.

Chapter 2

Background and Related Work

In this chapter relevant concepts and techniques with regard to habit formation are described. This is followed by an analysis and discussion of related work in both the domains of habit formation apps and sleep hygiene apps.

2.1 Background

The following paragraphs define the terms *habits*, *routines*, *implementation intentions*, *habit-stacking* and *habit-tracking*, and how they are related to each other. Furthermore, since the proposed solution is based on a smartphone app, the relationship between smartphone usage and sleep is described.

2.1.1 Habits and Routines

A *habit* can be defined as a learned action that is performed automatically in response to a specific cue [16]. A *cue* can refer to anything that acts as a trigger for the habit (e.g., contextual object or event). Whereas other work uses the terms *habit* and *routine* interchangeably, in this work the term *routine* is used to describe a set of actions that are performed regularly at a specific point in time (e.g., morning routine or evening routine) [17]. A *habit* thus refers to a single behaviour, whereas a *routine* refers to a set of habits (e.g., brushing teeth is a habit within an established evening routine). A habit is acquired by incrementally strengthening the connection between a cue and an action. The more frequently an action is performed in response to a specific cue, the more likely it is to become habitual [18]. However, the connection between how often a behaviour is repeated and its automaticity (i.e., how habitual it is) is non-linear [19, 20, 21, 22]. This indicates that repetitions earlier in the habit formation process strengthen the connection between cue and action more than later repetitions [19, 23]. The habit formation process is subject to high variation. Past research has shown that it takes individuals an average of 66 days to form a new habit with values ranging from 18 to 254 days [19]. The duration or amount of repetitions required for a habit to form is affected by various factors including the complexity of the new behaviour [19], the time of day it is performed [20] or whether early repetitions lead to positive or negative emotions [24]. A number of techniques have been developed to facilitate and support the process of habit formation. These are described in the following paragraphs.

2.1.2 Habit Formation Techniques

The following three techniques can be used to support the habit formation process. Whereas implementation intentions and habit-stacking are techniques that are used *before* the new behaviour is performed, habit-tracking is used *after* it was performed.

Implementation Intentions. To start the habit formation process, the desired action needs to be performed whenever a given cue occurs in the context. Consequently, this requires remembering to perform the intended action. Formulating *implementation intentions* is a technique that has been proven to help to remember to perform an intended action in relation to a specific situation. More specifically, it is a method to support the translation of goals into action by connecting an anticipated situation (cue) with an action that helps to attain a specific goal [25]. The intentions take the form of *"Whenever situation X occurs, I will perform action Y"* [26, p. 493]. A wide range of research supports the claim that implementation intentions have a positive effect on general goal attainment [27]. In the domain of habit formation, implementation intentions have been used effectively to promote healthy eating behaviours [28], promote physical activity [29], help smokers quit [30] and form a flossing habit [31]. Implementation intentions are effective because they facilitate the detection of the specified cue in the environment [32, 33]. Or in other words, they help to detect the situation in which the new behaviour should be performed. However, choosing an appropriate cue for the new behaviour affects the success of the technique. Event-based cues (e.g., arriving at home) are more effective in eliciting the intended behaviour in comparison to time-based cues (e.g., at 5 pm). The latter requires constant monitoring to identify the appropriate opportunity to act (i.e., checking the time at appropriate intervals) whereas the former does not [34]. Therefore, it is argued that distinct events in daily life that are unlikely to be missed are the most effective cues [35]. Existing habits represent a subset of these distinct daily events and are therefore a prime candidate for implementation intentions, as described in the following paragraph.

Habit-Stacking. *Habit-stacking* refers to a special form of implementation intention in which an existing habit is used as a cue to trigger a new behaviour: *"After/Before [current habit], I will [new habit]"* [36]. The term itself was coined by James Clear in his bestselling book "Atomic Habits" [37] and is based on the idea of "anchoring" proposed by Fogg [38]. Both authors claim that using existing habits as cues is an easy and effective way to form new habits [37, 38]. This claim is supported by research examining effective strategies for habit-formation that concludes that integrating a new behaviour into a pre-existing everyday routine will increase the likelihood of consistent repetition and can thus lead to habit formation [39, 40, 41, 42]. To distinguish the terms in this work, the term *habit-stack* refers to a combination of an existing habit with a new behaviour whereas the term *implementation intention* specifically refers to the sentence that captures the intention of performing the habit-stack.

Habit-Tracking. The term *habit-tracking* refers to a special form of *self-monitoring* which involves keeping a record of whether an existing habit (or a desired future habit) has been performed. Self-monitoring (sometimes also referred to as self-tracking or self-recording) plays an important role in the behaviour change process [43] and interventions involving it are significantly more effective than interventions without it [44]. In the context of habit-stacking, habit-tracking plays an important double role: First, it can be used to help identify opportunities to perform a new behaviour when applied to existing habits. Second, it can be used to draw attention to the new behaviour to monitor the compliance with the goal of forming a new habit [35]. Furthermore, keeping track of the performance of the new behaviour provides feedback which can lead to positive reinforcement to help people stay motivated during the habit-formation process [35].

2.1.3 Relationship between Sleep and Smartphone Usage

Technology usage in general and smartphone usage in particular interfere with both sleep quality and quantity, especially when used before or after trying to fall asleep [45]. This can be partly explained due to the blue-light emitting displays commonly used by many portable devices and their disruptive effects on the circadian rhythm and the expression of a sleep related hormone called melatonin [46, 47, 48]. More specifically, using electronic devices before bedtime increases the time it takes to fall asleep, reduces the amount of rapid eye movement (REM) sleep, and reduces alertness on the next morning [48]. Moreover, it is not only the usage of the device itself that can have detrimental effects on sleep quality. Mobile devices are commonly used to access social media which in turn is linked to a wide range of sleep disorders such as finding it difficult to fall asleep, waking during the night and deteriorating overall sleep quality [49, 50, 51]. Especially social media use before bedtime is associated with poor sleep quality [50, 52]. In summary, the relationship between IT use and sleep disturbances is multifaceted and so far three mechanisms have been proposed to explain it: (1) direct displacement (i.e, reduced sleep time due to time spent using IT), (2) poor sleep hygiene due to psychological and physiological effects (i.e., emotional arousal due to social media use) and (3) alterations of circadian rhythm (i.e., due to suppression of melatonin caused by screen light) [53]. Since the proposed solution is based on a smartphone app, these aspects must be taken into consideration when designing a smartphone based sleep intervention.

2.2 Related Work

Since the proposed solution in this work focuses on sleep hygiene recommendations, this section first introduces existing solutions in the domain of sleep hygiene apps and their limitations. Subsequently, existing solutions in the domain of habit formation apps are discussed to guide the design of the proposed solution.

2.2.1 Existing Sleep Hygiene Apps

Smartphone apps have been effectively used to track and analyse sleep patterns [54, 55], provide guidance with sleep related issues [56] and experiment with different sleep hygiene interventions [57, 58]. Also for more severe cases of sleep related issues (e.g., symptoms of insomnia), apps have been used to improve sleep quality [59, 60, 12]. There is a large number of available sleep hygiene recommendations which consist of small behaviour changes that are proven to increase the quality of sleep when they become habitual (e.g., disconnecting from devices 30 minutes before going to bed) [61, 62, 63]. These recommendations have been incorporated into apps to successfully support or fully deliver Digital Cognitive Behavioural Therapy (dCBT) [64] for insomnia. The sleep hygiene recommendations are usually augmented with graphics, interactive and animated videos, visualisations, a sleep diary and reminders in the form of smartphone notifications [12].

However, by solely relying on self-tracking and reminder functionality these apps suffer from problems of adherence and do not address the challenge of incorporating and sustaining the behaviour into users' daily lives and routines [12]. A similar analysis focusing on sleep apps in general also concluded that existing apps do not sufficiently support sustainable sleep hygiene patterns [11]. Knowledge about proper sleep hygiene is not necessarily sufficient to improve sleep quality, whereas practising proper habits is strongly related with an increase in sleep quality [65]. Consequently, sleep hygiene recommendations could benefit from additional guidance regarding both how to implement them in the specific context of an individual [9] and how to make them habitual. The importance of addressing existing habits to increase the adherence of new

behaviour has been identified before [40] but has not yet been incorporated into existing sleep related digital health interventions. The solution proposed in this work addresses these limitations by leveraging existing habit formation techniques to guide the behaviour change process.

2.2.2 Design Recommendations for Habit Formation Apps

This section discusses related work in the domain of habit formation apps to identify what approaches sleep related apps could take to leverage habit formation techniques to increase their effectiveness. In a review of 115 habit formation apps available in Apple's App Store[1] and Google's Play Store[2] Stawarz et al. [66] identified that existing solutions focus mainly on self-tracking and reminder functionality and do not support event-based cues (i.e., existing habits). Therefore, they concluded that available apps are not grounded in the habit literature. Based on their analysis they identified a number of design recommendations for designing apps that support users in building daily routines. These recommendations are summarised in Table 2.1 and augmented with related findings from the existing literature on habit formation apps.

#	Design Recommendation	Source
DR1	Users should be able to specify their existing routine.	[40]
DR2	Users should be provided with examples of 'good' cues to help them define their own.	[67]
DR3	Users should be able to select trigger events (i.e., existing habits) as cues to trigger the new behaviour.	[66, 15]
DR4	Users should be encouraged to identify and use additional cues.	[68, 15]
DR5	Users should be able to form implementation intentions.	[69, 15, 70, 71]
DR6	Users should be reminded about the implementation intentions before the selected trigger event occurs.	[72]
DR7	Implementation intention reminders should prompt the user to actively rehearse the intention.	[70]
DR8	Implementation intention reminders should be phased out after a while to prevent dependency.	[66]
DR9	Users should be asked later if the task was completed (i.e. no same-day habit tracking.)	[66]

Table 2.1: Design recommendations for habit formation apps based on existing literature.

[1] https://www.apple.com/app-store/
[2] https://play.google.com/store/apps

2.2.3 Existing Habit Formation Apps

The following paragraphs summarise the findings of related work in which the concepts introduced in Section 2.1 are used to support habit formation using a smartphone app. Furthermore, limitations of the existing work with regard to the design recommendations (see Table 2.1) are discussed.

Smartphone Detectable Cues & Implementation Intentions. Pinder et al. [69] created an app that allows users to combine a contextual cue with a new behaviour through forming implementation intentions. While this work demonstrated the feasibility of an app that supports implementation intentions in combination with just-in-time reminders, it did not address the potential problem of users developing a strong dependence on the app's reminders. Furthermore, the cues were limited to ones detectable by the smartphone (location, movement, time, calendar, device battery and orientation) and thus did not include event based cues.

Event-based Cues & Implementation Intentions for Mood Journaling. Wicaksono et al. [70] created an app that allows user to specify an existing habit as a trigger for filling out a daily mood report. Additionally, the app sent users reminders about the implementation intention at lunch time (e.g., "Remember to report your mood after arriving at home in the evening"). Their findings suggest that sending reminders as reinforcements for the implementation intentions improves compliance of users to the new behaviour. However, their work was limited by allowing users to exclusively form a mood journaling habit and thus did not address potential challenges in the habit formation process for other habits. Furthermore, the reminders for the implementation intentions did not encourage users to actively rehearse the intention which could increase their effectiveness.

Event-based Cues & Implementation Intentions for Meditation. Stecher et al. [71] conducted a randomised control trial that used an existing mobile meditation app to help people establish a daily meditation practice by relying on existing habits as cues. Similar to other work, users received a daily reminder notification at a random time. The results of their trial show that participants who performed the meditation in connection with an existing habit had a more persistent meditation routine than the control group who did not combine it with an existing habit. While their work provides evidence that habit-stacking and implementation intentions can support habit formation with an existing meditation app, they did not address how these techniques can be integrated into the app itself or how they might be applied to different habits that are not performed in connection with the existing meditation app.

Event-based Cues & Habit-Tracking for Study Habits. Stojanovic et al. [21] created a smartphone app to help students form new study habits (e.g., reading relevant literature) by tying it to an existing daily activity (e.g., after eating breakfast). The app sent daily reminders to the users to perform the new habit and users were able to track their progress within the app. However, the app did not prevent users from scheduling just-in-time reminders for their new habit, did not make use of implementation intentions and relied on same-day habit-tracking.

None of the solutions described above incorporates all design recommendations identified in the existing literature (see Table 2.1). Only a few solutions try to address the problem of users forming a dependency by relying on just-in-time reminders and the ones that do are either focusing on a specific habit or do not incorporate the aspect of habit-tracking. The solution proposed in this work addresses these limitations by combining habit-stacking, habit-tracking and reminders for implementation intentions in a way that aims to limit the problem of dependency.

Chapter 3

Methodology

To answer the research questions, an initial literature review was conducted to elicit design recommendations based on prior work in the habit formation literature. To incorporate these design recommendations and to address shortcomings of existing solutions, a smartphone app named *Habstack* was created. To evaluate the solution and to gain insights into users' real-world experience with the app, a two week study was conducted in which user data was collected and participants were interviewed about their experience. The following sections describe the approach in more detail.

3.1 Habstack Smartphone App

The Habstack app incorporated the concepts introduced in Section 2.1 and supported them using technology. Figure 3.1 displays an overview of the habit formation techniques used and how they were supported in the app. The design of the app is based on a five step process, in which each step corresponds to a different technique. The following sections describe each step and explain how the design recommendation from the existing literature guided the design of the functionality. The steps are listed in the order they are presented to the user and thus represent the user flow through the app.

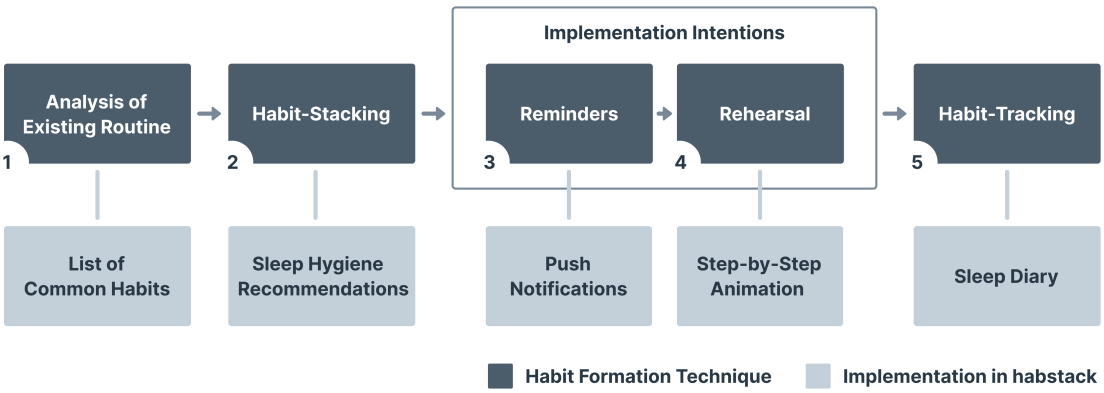
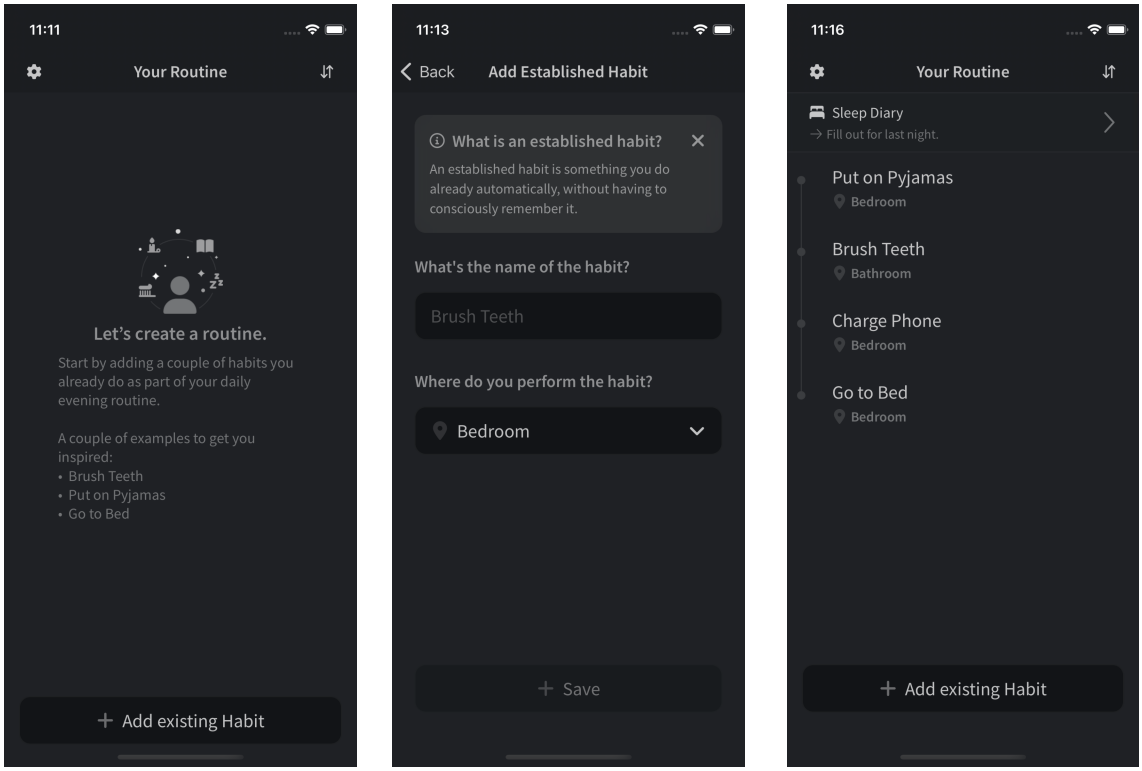


Figure 3.1: Overview of habit formation techniques and their implementation in the app.

3.1.1 Input of Existing Routine

In a first step[1], users were tasked with analysing their existing sleep hygiene routine by identifying habits that they consistently do. To guide this process, the app presented three suggestions (*Brush Teeth*, *Put on Pyjamas*, *Go to Bed*) as seen on Figure 3.2a. For each existing habit, users could provide a name and a context in which the habit was performed from three predefined options (*Bedroom*, *Bathroom*, *Other*) as seen on Figure 3.2b. After entering the habits, the app presented them in a vertical timeline as shown on Figure 3.2c. For the study, users were required to capture at least one existing habit but the app did not restrict the amount of habits users could enter. Furthermore, the app provided options to change the order of the habits, edit the details and remove habits. In combination, the three screens shown in Figure 3.2 satisfy DR1 and DR2 by allowing users to specify their existing routine and by providing examples of cues to help them define their own.



(a) Emtpy *Your Routine* screen with an explanation on how to add existing habits

(b) Screen to add an existing habit

(c) *Your Routine* screen displaying a timeline of the existing habits

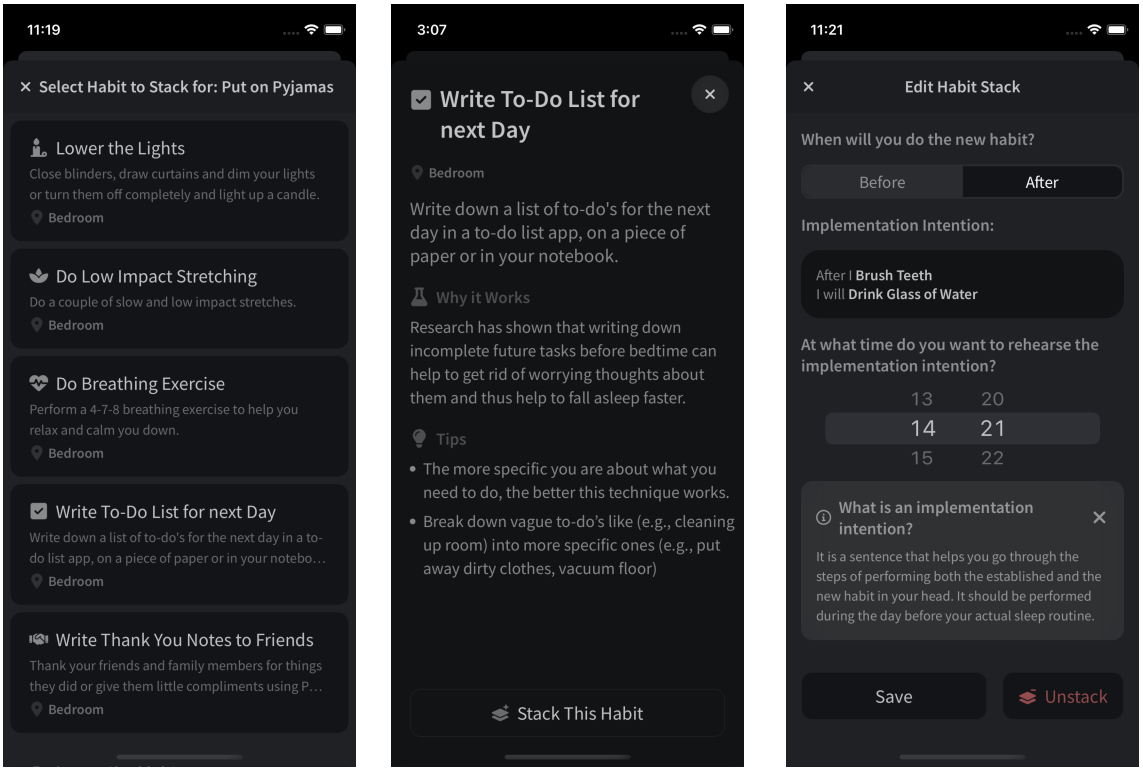
Figure 3.2: Overview of screens that allow the capturing of existing habits.

[1]The app also included a number of onboarding screens that guided the users through the setup of the app after its initial launch (see Figure A.1 in Appendix A).

3.1.2 Habit-Stacking

In a second step, users could use the existing habits to form habit-stacks. A habit-stack consisted of an existing habit that acted as a cue for a new behaviour (DR3). After selecting an existing habit, the users were presented with a list of sleep hygiene recommendations (Figure 3.3a). The recommendations were sourced from the existing scientific literature on sleep hygiene and vetted by a professional in the field. All recommendations are listed in Table 3.1 with their corresponding sources. After selecting a recommendation, a screen provided more information about the new behaviour, including an explanation of why it works and additional tips on how to implement it (Figure 3.3b).

This was followed by a screen to configure the habit-stack (Figure 3.3c). Users could select whether they intended to perform the new behaviour *before* or *after* the existing habit. Furthermore, they were presented with a preview of the implementation intention that they would later rehearse to remember to perform the new behaviour (DR5). To schedule the push notification reminders for the rehearsal, users could select a custom time. If the users selected a time that could be part of their evening routine (i.e., after 8pm), the app displayed a warning message, encouraging users to schedule the reminder during the day instead (DR6).



(a) Screen to select a sleep hygiene recommendation

(b) Screen with additional information about the recommendation

(c) Screen to configure the habit-stack

Figure 3.3: Overview of screens allowing the formation of habit-stacks with corresponding implementation intentions.

Recommendation	
Bedroom	
Lower the Lights [73]	Do Low Impact Stretching [74]
Do Breathing Exercise [75]	Write To-Do List for next Day [76]
Write Thank You Notes to Friends [77]	Re-Watch Movies or Episodes of Series [78, 79]
Shred old Bills and Statements [80]	Fill out Gratitude Journal [81, 82]
Drink Glass of Water [83]	Quiet Reading [84]
Listen to Soothing Music [85]	Write down Thoughts in Journal [86]
Prepare Clothes for Tomorrow [80]	Clean up Room [87]
Open Window [88, 89]	Add Scent of Lavender [90]
Bathroom	
Take a Warm Shower / Bath [91]	Pedicure / Manicure / Skin Care [80]
Floss [80]	
Other	
Go for a Walk [92]	

Table 3.1: List of sleep hygiene recommendations in the app based on existing literature grouped by context.

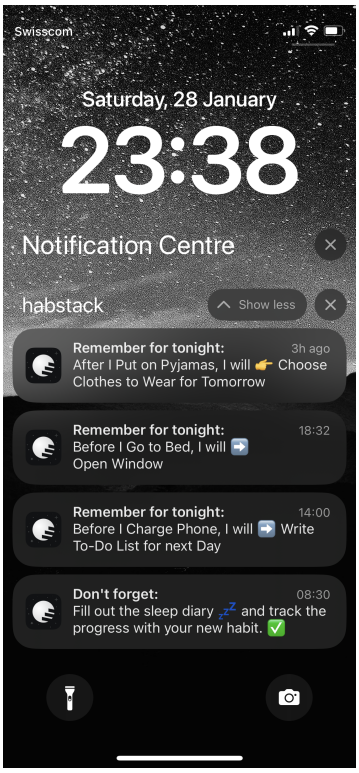
3.1.3 Implementation Intention Reminders & Rehearsal

On a daily basis, users received a reminder to rehearse their implementation intention at the time specified during the configuration of the habit-stack. The reminders were delivered using push notifications and contained the implementation intention sentence (Figure 3.4a). For each habit-stack created in the app, the user received a distinct reminder. When a notification was tapped, the app was opened and the user was presented with a screen to rehearse the sentence (Figure 3.4b). Upon entering the screen, a step-by-step animation of the sentence was displayed. The sentence was divided into four parts: timing (*"Before / After I"*), existing habit (*"Brush Teeth"*), intention (*"I will"*) and new behaviour (*"Drink Glass of Water"*). The parts were animated to fade in one after the other with a delay (1s), giving a total duration of 5s for the animation. A button was present to confirm the rehearsal of the sentence at the bottom of the screen.

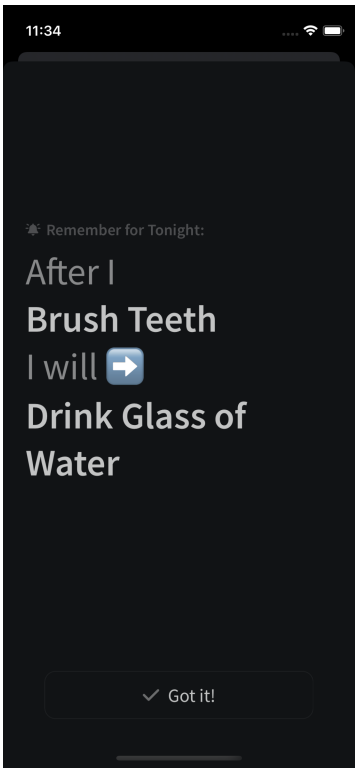
3.1.4 Habit-Tracking & Sleep Diary

In a last step, users were tasked to fill out a daily sleep journal that allowed the tracking of sleep related metrics and the adherence to the new behaviour. At a customisable time in the morning, users received a daily reminder to complete the sleep diary for the previous night (last notification at the bottom in Figure 3.4a). The screen was divided into two parts. The top part listed all habit-stacks that were formed in the app. For each, users could tick a box to indicate whether they had performed the new behaviour the previous evening (Figure 3.5a). Based on this, the app calculated a habit strength score[2] for each habit-stack.

[2]The following formula was used for its calculation: $\frac{1}{66} \times$ number of repetitions. Resulting in the strength reaching 100% after 66 repetitions referring to the median amount of daily repetitions required to form a habit [19]. As the study to evaluate the app lasted for less than 66 days, users would never reach 100%, so the score was only a simple proxy to give users an indication of their progress with the new behaviour. Accurately measuring and representing habit strength requires more sophisticated tools (e.g. Self Reported Behaviour Automaticity Index [93]) and is still subject to discussion in the literature [94].



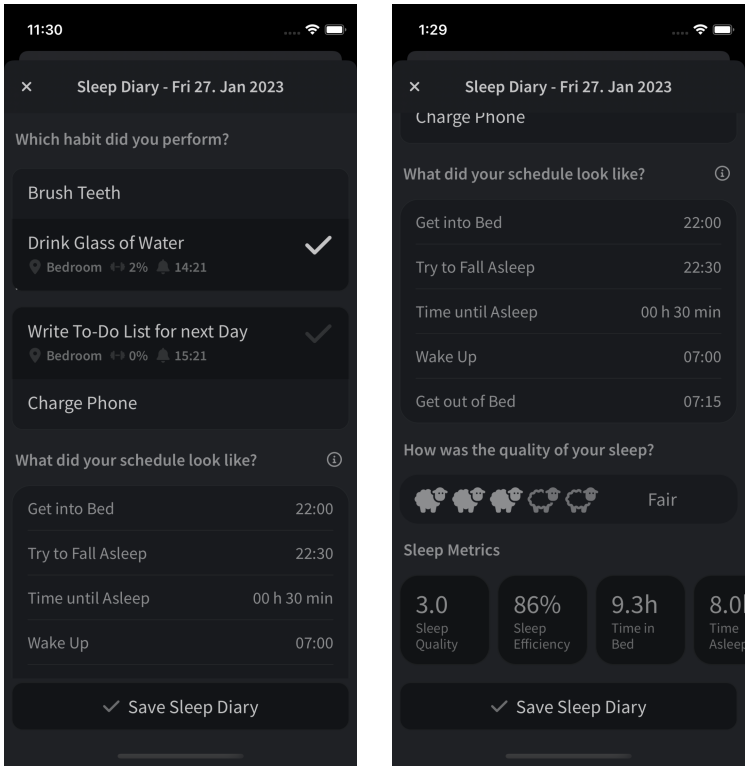
(a) Push notification reminders for the rehearsal



(b) Screen to rehearse implementation intention

Figure 3.4: Implementation intention reminders and rehearsal screen.

The bottom part allowed users to enter six different values, based on which a number of sleep metrics were calculated (Figure 3.5b). The six values[3] were derived from the Consensus Sleep Diary which represents a standardised sleep diary that can be used to capture sleep related data [95]. It has been successfully used in electronic form before [96] and can provide more accurate results than other smartphone based forms for measuring sleep [97]. Based on the six values the app calculated and displayed five sleep metrics: *Sleep Quality* (score based on the quality reported in the last item ranging from one [very poor] to five [very good]), *Sleep Efficiency* (percentage of time asleep out of time spent in bed), *Time in Bed* and *Time Asleep* [95]. The sleep diary entries were saved and could be edited on the same day. The app did not provide options to add, edit or remove past sleep diary entries.



(a) Habit-tracking part (top) **(b) Sleep diary part with metrics (bottom)**

Figure 3.5: Screen for habit-tracking and sleep diary.

[3]The full version of the sleep diary contains nine values in total. Two items relating to the number and duration of night-time awakenings and one item relating to general comments were omitted in order to reduce the effort required to complete the diary while still capturing the most relevant metrics.

3.2 Application Development

The Habstack app was developed using a two-step process. First, an interactive prototype for the app was built which was then turned into a fully functional smartphone app for the *iOS* operating system. The following two sections describe these two steps in more detail. The last section describes how the usage data in the app was captured and monitored during the study using a custom built dashboard.

3.2.1 Design Process

To test the usability of the implementation of the design recommendations and to experiment with different design choices, an interactive prototype of the app was created using the collaborative interface design tool *Figma*[4]. The design of the app was refined iteratively, starting with a low-fidelity design to define the general structure of the app, which was then turned into a high-fidelity interactive prototype that could be run on a real device. The final prototype was evaluated within the research team and with an additional test user who provided feedback on the user experience. This process helped to identify and resolve usability issues and to test whether the design of the app was able to convey the habit-stacking technique in an intuitive way. Even though the functionality of the app was designed to not require any interaction with the app during the evening routine, the user interface of the app was still designed to address the low-light situations in which it might potentially be used. The user interface employed a dark colour scheme which reduces visual fatigue and improves the usability in dark environments [98].

3.2.2 Architectural Decisions

The smartphone app was developed using the open-source framework *Expo*[5] which facilitates the development and distribution of apps for multiple devices. It is based on the *React Native*[6] framework which allows the development of cross-platform apps using the *JavaScript* language. To store the user data entered in the app in anonymized form, Google's real-time database *Firebase*[7] was used. Finally, the app was distributed using Apple's *TestFlight*[8] tool which facilitates the invitation of test users and the testing of apps for the iOS ecosystem. Combined with the Expo framework, this allowed updates to the app to be distributed over the air without the need for users to manually reinstall the app. During the development process and the study, the error reporting tool *Sentry*[9] was used to capture and monitor errors in the app.

3.2.3 Monitoring and Analysing Usage Data

To monitor and analyse the data collected in the app, a dashboard was built that displayed the information captured in the app for each participant of the study. The dashboard was built as a web application with the *React* frontend framework using the *JavaScript* language. The dashboard was connected to the same real-time database as the app. An overview of the captured data and how it was presented on the dashboard is shown in Figure 3.6. This dashboard was used to analyse the app data and to identify usage patterns which were then discussed with the study

[4] https://www.figma.com
[5] https://expo.dev
[6] https://reactnative.dev
[7] https://firebase.google.com
[8] https://developer.apple.com/testflight/
[9] https://sentry.io/

participants during the user interviews (e.g., to address consecutive days where the habits were not performed). The dashboard displayed all the existing habits and habit-stacks that the users captured in the app. Furthermore, for each habit-stack it visualised the habit-tracking data and whether the implementation intention rehearsal was completed.

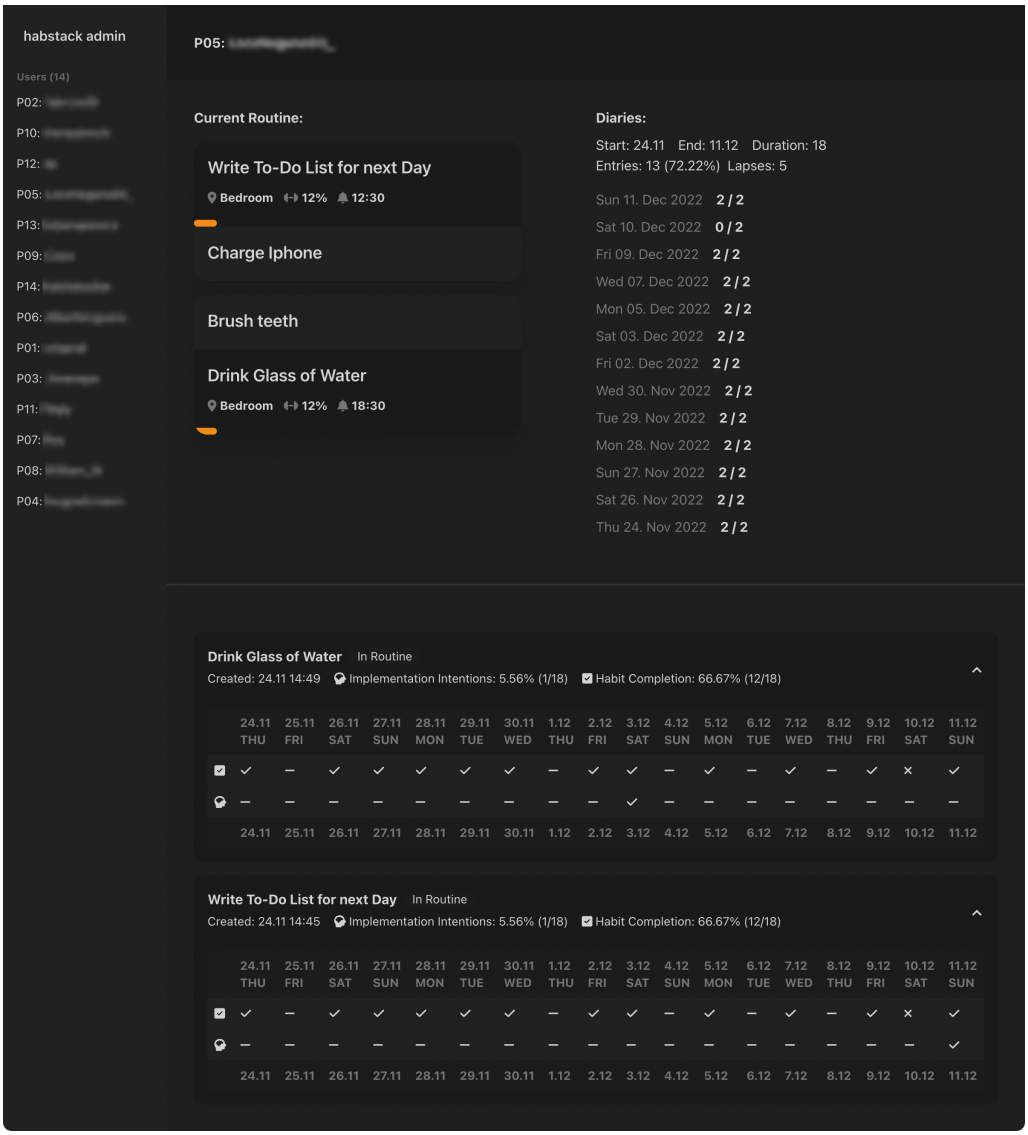


Figure 3.6: Dashboard built to monitor and analyse the data collected in the Habstack app. The usernames have been blurred to protect the privacy of participants.

3.3 User Study

To evaluate the Habstack app and to gain insights into users' experience with it, an exploratory study was conducted. It included a pre-study survey to screen participants, an onboarding session to guide the installation process of the app and concluded with a final interview. The following sections describe the demographics of the participants and the steps involved in the study in more detail.

3.3.1 Participant Recruitment and Demographics

Participants were recruited using the personal network of the researchers and by advertising the study in a chat group for master students in the field of information technology at the University of Zurich. Anyone between the age of 18 and 65 who possessed an iPhone and has not been diagnosed with any sleep related health issue (e.g., insomnia) was eligible. In total, 15 people filled out the pre-study survey and installed the app out of which 14 were interviewed at the end. The person that was not interviewed did not use the app after the initial onboarding. The following demographic data refers to the participants performing all steps of the study including the final interview (n = 14).

To screen participants, an online survey was conducted prior to the study. It included three questions about demographics: age, gender and occupation. Additionally, it asked whether existing tools to track sleep or form habits were used. Lastly, it included a question about whether a sleep related issue had been diagnosed before. Participants were aged 24-31 years (Mean = 27.1, SD = 2.0), with 10 participants identifying as male and 4 as female. All participants were university educated (3 master students, 3 software engineers, 2 startup founders, 2 therapists, 2 marketing managers, 1 doctoral student, 1 lawyer) and had not been diagnosed with sleep related issues before. Only one participant reported currently using another sleep tracking app. No participant reported currently using another habit-formation app.

After filling out the pre-study survey, participants gave their consent to participate in the study by signing a consent form that informed them about the proceedings of the study, what data would be collected and in what way it will be used for the study (see Appendix C). Subsequently, they received a link with information on how to install the app on their smartphone. Afterwards, participants were contacted individually and guided through the initial setup of the app during a 10-15 minute onboarding video call.

3.3.2 Evaluation of the App

After the onboarding, the users were tasked with evaluating the app. Participants were free to choose the start and end date of the evaluation period, as long as it included a minimum of 14 consecutive days in which they tried to use the app on a daily basis. Most participants used the app for 15 consecutive days (Mean = 17.4, SD = 4.7, Min = 15, Max = 31). The users were instructed to form at least one habit-stack by entering an existing habit and selecting a recommendation from the list. Additionally, they were asked to fill out the sleep diary on a daily basis and were informed that they will receive daily reminders to rehearse the implementation intentions for their habit-stacks.

3.3.3 Final Interview

A final semi-structured interview was conducted with each participant at the end of the study. The interviews were conducted by the researcher. They were structured using an interview script that included both open-ended questions about the participants experience with the app and questions tailored to their specific usage of it (e.g., *"You have stacked [new habit] on top of [established habit]. Why did you choose the new habit and why did you select the established one?"*). The full interview script is available in Appendix D.

The interviews were held in Swiss German, German and English depending on the native language of the participant. The interviews lasted between 27 and 58 minutes with an average duration of 39 minutes (SD = 10 min) and were recorded (audio only) with the permission of the participants. 12 out of 14 interviews were conducted using a video conferencing tool and the remaining two were conducted in person.

3.3.4 Data Analysis

The study involved both the analysis of qualitative data captured during the interviews and quantitative data captured in the smartphone app. The following paragraphs describe how both datasets were analysed.

Qualitative Analysis. The recordings of the interviews were transcribed and imported into a spreadsheet software for further analysis. Interviews held in Swiss German were translated to German by a native speaker. Subsequently, the interview statements were analysed using thematic analysis [99] by the same researcher. The interview data was coded to identify themes in relation to the research questions, thus following a more theoretical approach. After generating codes, recurring themes were identified and statements were grouped according to the themes. Finally, the themes were revised and prioritised based on their relevance for answering the posed research questions. The results of the thematic analysis are reported in English. To ensure the validity of the translation, statements that required translation into English prior to inclusion in this work were translated by the researcher, who is a native speaker of both Swiss German and German.

Quantitative Analysis. The usage data captured in the app was analysed using the custom built dashboard (see Section 3.2.3). The dashboard displayed all data captured in the app and calculated summary statistics such as habit adherence rate, implementation intention rehearsal rate and sleep diary completion rate. These values were then transferred into a spreadsheet software to calculate aggregate statistics for all users.

Chapter 4

Results

The following sections summarise the quantitative usage data collected within the app and the qualitative findings from the interviews conducted at the end of the user study. The first section captures findings related to the analysis of the existing routine, which is a necessary prerequisite for habit-stacking (RQ1). The second section focuses on themes identified specifically in relation to habit-stacking (RQ1). This is followed by a section outlining the findings surrounding implementation intentions rehearsal and their reminders (RQ2). Finally, findings on the impact of using the app to support users in developing better sleep routines are described (RQ3).

4.1 Analysis of Existing Routine

As a first step, participants were tasked with analysing their existing sleep hygiene routine. This included, becoming aware of habits that are executed on a daily basis before going to bed and capturing them in the app. Most participants were able to identify at least 3 habits (Mean = 3.36, SD = 1.39, Min = 2, Max = 6). In total, 24 distinct existing habits were captured. Table 4.1 shows all existing habits captured in the app and how often they were reported. The table highlights the wide range of behaviours that are part of participants' existing routines. The following paragraphs summarise findings related to the analysis of the existing routine.

F1: Existing habits can be difficult to elicit due to their automatic nature.

During the interviews, participants reported that at the beginning of the study they had difficulty reflecting on their habitual actions during their evening routine.

> "I haven't found it easy to find something I really do every day in the evening." - P1

> "What I'm realising just now is, that I am sometimes not aware of what I am doing [referring to existing habits]. These are such simple things but they are so unobtrusive in my daily life and take up so little time that they didn't even occur to me." - P12

F2: Identifying existing habits can be facilitated by providing a list of common habits.

When provided with more examples of habits during the final interview (based on other participants' routines) participants were able to quickly identify the ones that were also part of their routine. Participants also reported that their existing routine consists of undesired habits (i.e., habits they want to get rid off). A lot of examples included the usage of smartphones or other devices either in bed or close to bed time. Furthermore, *unstable* habits were mentioned that are

Existing Habit	Count		
Brush Teeth *	14	Read News	1
Charge Phone	7	Clean Face	1
Go to Bed *	4	Put Phone in Flight Mode	1
Put on Pyjama *	2	Take Off Clothes	1
Set Alarms	2	Check Instagram	1
Pet Cat	1	Go to Bedroom	1
Plan Train Connections	1	Turn Off Lights	1
Hug Boyfriend	1	Wash Face	1
Watch TV	1	Pack for next Day	1
Watch Videos Online	1	Shower	1
Check Twitter	1	Check Messages	1
Make a To-Do List for Tomorrow	1	Remove Makeup	1

Table 4.1: List of all existing habits captured by participants using the app. Habits marked with * were provided as default values within the app.

part of the routine but are not performed on a daily basis. Examples include *playing an instrument*, *meditating* or *drinking a glass of water*. Whereas some participants wanted to strengthen these habits to make them more stable, others were fine with keeping them as occasional habits. This coincides with the next finding regarding the stability of the existing routine and its habits.

F3: Stability of existing routine is affected by various factors.

During the interviews, participants mentioned a number of factors that impacted the adherence to the routine captured within the app as summarised in Table 4.2. Common themes were the presence of visitors or spouses during the evening, deviations from usual schedule (e.g., due to unplanned late night work), evening activities such as sports or social events, being in a different location (e.g., due to travelling or sleeping at spouse's place) or lifestyle changes in general (e.g., change of job).

4.2 Habit-Stacking

The app supported habit-stacking by allowing participants to stack a new action based on a list of suggestions on top of their existing habits. For the study, participants were asked to form at least one habit-stack. More than half of the participants formed two or more stacks and some participants formed up to four stacks (Mean = 1.86, SD = 1.03). Based on the quantitative usage data captured in the app, the average completion rate for the new behaviour (i.e., times new behaviour was performed / total amount of days) was 53.3% (SD = 28.21%) ranging from 0% for participants never performing the new behaviour to 100% for participants always performing it.

A visualisation of the adherence to the new behaviour of the participants is shown in Figure 4.1. The new behaviours are shown on the y-axis grouped by participant. Coloured boxes mark all the days where the new behaviour was part of the routine in the app (i.e., planned to be performed by the participants). The colour codes indicate whether the new behaviour was marked as completed / not completed or if there was no data for that day (i.e., the participant did not fill out the sleep diary on that day). Boxes marked with a grey circle are days where the participant also completed the implementation intention rehearsal in the app. At the end of each line the completion rate for the new behaviour and the implementation intention rehearsal are displayed.

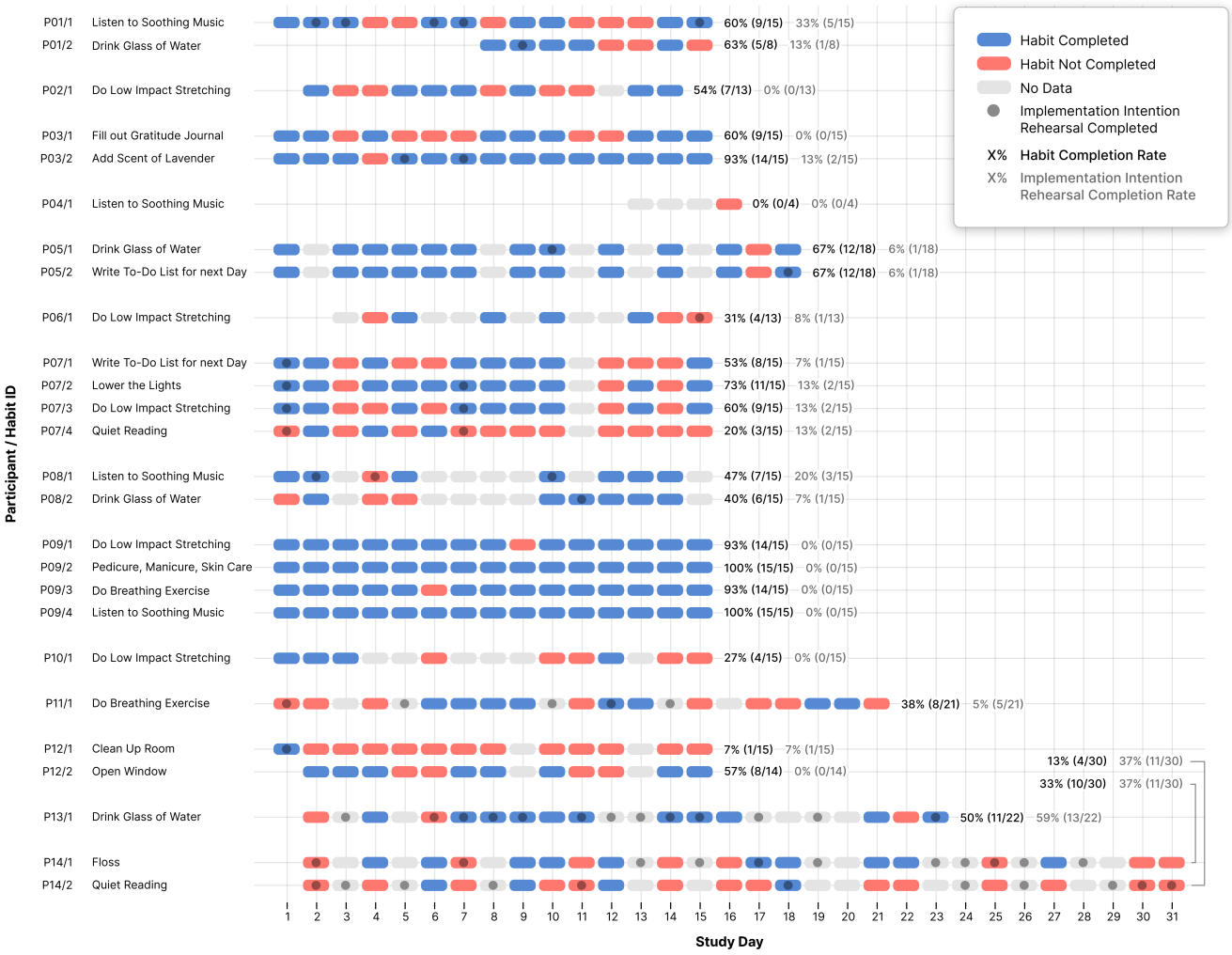


Figure 4.1: Visualisation of participants' adherence to new behaviour and implementation intention rehearsal during user study.

Factor	Example
Presence of People (Visitors, Spouses)	"Actually, I always do things [referring to existing habits]. But when, for example, my girlfriend was with me, I thought about it less. It came to my mind less than when I was alone." - P11
Deviation From Usual Schedule	"There are days where I've worked until 3 or 4 in the morning. And that's not optimal for my sleep rhythm. And on those days I didn't do the habit because I had other things on my mind." - P10
Evening Activities	"I have [sports] training twice a week and my evening routine is completely different after training." P1
Different Location / Environment	"It has more to do with the fact that I don't sleep at home in these instances. When I am at home, then it came to my mind easier, because I have established more of a routine there." - P12
Lifestyle Changes	"My sleeping habits have also just changed. It has to do with my new job. I am very tired right now. Sometimes I managed to leave the music on but sometimes I just went straight to sleep." - P4

Table 4.2: Factors impacting existing routines with example statements provided during the interview

After finishing the user study participants reported mixed experiences with the habit-stacking technique. Some participants reported that they had the impression that a connection between the two behaviours was established, whereas others reported that this was not the case.

> "Yes, so I brushed my teeth and then thought: 'Ah, I should still be flossing'. That is actually how it went. So not that I kind of looked at the app or anything." - P14

> "I think I just had it in the back of my mind. I think the association was not strong enough. I was thinking more about it because I still have to do it in the evening. And then it occurred to me: 'Ah yes, it is coupled with that [referring to existing habit].'" - P12

When asked about specific reasons for why the habit-stacking might not have worked, a number of factors were identified, as described in the following paragraphs.

F4: Stability of existing habit affects success of habit-stacking.

The success of habit-stacking depends on the stability of the existing habit chosen as a cue for the new behaviour and on the stability of the existing routine. Participants who did not have a stable routine and did not perform the existing habit regularly also reported that habit-stacking did not work.

> "For someone who doesn't have a very regular or consistent routine or even an established routine in the evening, it's been difficult to tie it to a habit that I really do every day." - P12

This can be observed in Figure 4.1 for participant P4. They reported significant changes in their life as a result of a change of job, which had an impact on the stability of their existing routine.

F5: Complexity of new behaviour affects success of habit-stacking.

Another factor that mediated the success of habit-stacking was the complexity of the new behaviour. Participants that chose to build two or more habit stacks with different new behaviours reported, that simpler behaviours were easier to execute whereas more complex behaviours were perceived as a chore or too cumbersome.

> "It feels more like a "task". Something more that I have to do in my day. Whereas the other one does not. 'Adding a scent of lavender' was just spraying a bottle. It requires less than a second of your time. And does not involve a lot of thinking or processing." - P3

> "And it was also very "low effort" it doesn't normally cost me anything to turn off three out of four lights and only have the one next to the bed on." - P7

This pattern can also be observed in Figure 4.1. Both participant P3 and P7 formed multiple habit-stacks and had higher adherence rates for a new behaviour that was simpler in contrast to more complex ones (e.g., P03/1 in comparison with P03/2).

F6: Mental state & well-being of participants affect habit-stacking.

The mental state and well-being of participants seemed to have affected how successful a connection between the existing habit and the new behaviour could have been formed.

> "It depended on my mental state. If I wasn't completely exhausted, then the combination worked. So I wanted to charge my iPhone [existing habit] and then I noticed if I wrote my to-do list or not [new behaviour]." - P5

F7: Motivation and knowledge about benefits of new behaviour mediate habit-stacking.

Participants who reported having prior intentions and motivation to perform the new behaviour were also more successful with the habit-stacking technique. When asked about why they were motivated to perform the habit, they reported either having experienced or knowing about the benefits of the new behaviour.

> "I know in principle that [writing] a to-do list empties the head. The activity is not new, but I have not done it consistently before. But I already knew what the advantages are." - P5

Whether participants experienced positive benefits after performing the habit was another aspect that influenced their motivation.

> "The 'Drinking a Glass of Water' was therefore a good option, as I feel that I sleep better if I drink something beforehand." - P1

Conversely, participants who did not perceive any immediate benefits in performing the new behaviour lacked motivation to continue with it.

> "There was no sign for me that it changed anything. [...] It didn't have an impact in any way. Then it kind of went down [referring to motivation]." - P11

F8: Availability of additional cues can benefit habit-stacking.

Some participants reported that they used additional cues in their environment that reminded them to perform the new behaviour. In the case were these cues were present, participants reported that it helped them to be reminded about the new behaviour in addition to the existing habit.

> "And usually I create the circumstances / atmosphere that help me and remind me of the routines I need to do. So I just open Spotify on my iPad or on my phone and put it on my desk. So after I brush my teeth [existing habit] I can just see it and when I switch on the screen I just see it and listen to some music [new behaviour]." - P8

> "At my house, I have a little box next to the bed. And there I have the glass of water on it. And when I then charge the smartphone [existing habit], I thought about it - Ah I see the glass of water - and would still have to drink something [new behaviour]." - P13

F9: Matching contexts can facilitate habit-stacking.

Another factor that contributed to the success of habit-stacking was whether the contexts of the existing habit and the new behaviour matched. Participants who formed habit-stacks within the same context reported that it facilitated the process of forming the new habit.

> "When I charge my iPhone [existing habit], I also check my calendar and when I check my calendar, I can also capture a to-do right away [new behaviour]. It's relatively obvious. And so it's fallen into place relatively easily for me." - P5

In the example above both the existing habit and the new behaviour are performed on the phone which acts as a shared context for both.

F10: Habit-stacking can be successful even if new behaviour is not performed.

The habit-tracking feature of the app allowed participants to track whether they performed the habit on the evening before. However, as revealed during the interviews, not performing the habits did not mean that participants forgot about the new behaviour.

> "Often I even thought about it, but then thought I won't do it now. Because I was just too lazy or it had too little priority for me at that moment. [...] Exactly, so the reminder has almost always worked I must say. It was then more due to my discipline that I effectively didn't do it." - P10

> "I think sometimes I thought about it and then didn't do it because I didn't want to get up." - P13

> "I was just too tired. I didn't even forget, I just thought: I cannot do it anymore." - P9

As the examples above highlight, participants thought of performing the new behaviour but actively decided not to do so due to exhaustion or lack of discipline. In this regard, habit-stacking succeeded in helping them to remember the new behaviour even if it was not performed.

4.3 Implementation Intention Rehearsal

To support habit-stacking, the app made use of implementation intentions that were displayed as an animated sentence within the app. The app tracked the amount of times participants rehearsed the intention by looking at the animation. The average in-app rehearsal rate was 12.4% (SD = 14.8%, Min = 0%, Max = 59.1%). Most participants rehearsed their implementation intention just once at the beginning of the study and only few rehearsals were recorded afterwards. This pattern of the way implementation intention rehearsals were performed is also visible on Figure 4.1. The following paragraphs describe findings related to the experience of participants with this functionality.

F11: Implementation intentions and their rehearsal are perceived as helpful.

Generally, participants reported that they have perceived the animated display of the implementation intention in combination with a daily reminder as helpful to support them during the habit-formation process.

> "I felt like reading the sentence with a completely blank background, so I could just focus on that, worked well." - P1

> "Then when I clicked on it, I found it coherent. It was exactly what I needed to internalise the phrase." - P5

> "Yes, if you do the exercise, get the sentence in your mind. Then I think it leads to higher chance of the activity being performed." - P6

One participant could recall an instance where the phrase itself became conscious while performing the existing habit.

> "I can remember however that while brushing my teeth [existing habit] the phrase popped up." - P3

A number of different factors impacted the effectiveness of the implementation intention rehearsal as described in the following paragraphs.

F12: Impact of implementation intention rehearsal is mediated by active visualisation and attention during rehearsal.

Participants were asked whether they visualised the process of performing the existing habit and the new behaviour in their mind when rehearsing the implementation intention. Only a few participants reported that they have visualised performing both actions.

> "I tried to connect the app with the physical objects. I have tried to make the connection in my head: Whenever I brush my teeth, I still have to drink something. And: Whenever I plug the charger into my iPhone, I still have to write the to-do list." - P5

Although, most participants reported that they did not actively visualise the performance of the behaviours.

> "It was more of a reminder. I did not actively visualise anything. Maybe subconsciously, but not consciously." - P10

> "No, it was more linguistic. The idea didn't even occur to me. I imagine it could help, though." - P13

4.4 Implementation Intention Reminder

To remind participants about rehearsing the implementation intention (i.e. opening the app and watching the step-by-step animation) the app sent out a push notification per habit-stack at a time specified by the participant.

F13: Push notification reminders for the rehearsal of implementation intentions are perceived as helpful.

In general, participants perceived the reminders as helpful and non-intrusive, even when receiving multiple notifications due to having multiple habit-stacks configured in the app.

> "But the two notifications, I usually saw them more or less at the same time. This requires so little effort that I found it very pleasant." - P12

> "I found it very appropriate. [...] Once a day I think is good. If it comes too much, then you get annoyed. Once a day is fine." - P9

However, two factors impacting the effectiveness of the reminders could be identified. The first one is related to the timing of the notification and the second one to the way participants interacted with it.

F14: Effectiveness of implementation intention reminders is mediated by appropriateness of timing.

Participants could customise the time at which the notification with the reminder for the implementation intention rehearsal was delivered. Based on the responses of the participants the timing was appropriate when (1) it fit participants' schedule (i.e., they were able to look at the notification) and (2) it fit participants' state-of-mind (i.e., they perceived the notification as relevant).

> "And I deliberately chose 17:30 so that it's a time when I can look at the smartphone and I don't have the 'Do not Disturb' mode on. I chose the time so that I notice it directly when the notification comes." - P1

> "Because in the context where they came for me, they were not relevant for me. And then I fell back into my mental autopilot. [...] Yes, so I was in a completely different daily rhythm, completely different things were important." - P11

Consequently, participants who were successful in identifying an appropriate time slot also reported seeing the notifications more often. Some participants experimented with different timings for their notifications and reported that placing them later in the day after finishing their work seemed to have worked better.

> "18:00 worked better. At 12:45 I was still at work and still on lunch break. It's not as regular. Often I have the smartphone in the office and come back and just see it and then it has been less of a good fit." - P12

> "I think 19:30 had been better chosen. Because at this time I was not at work and also not at the university. So I had time to look at it effectively at the moment it comes and not afterwards." - P14

In addition to the timing, the effectiveness of the notifications also depended on the way the participants interacted with it on the smartphone.

F15: Implementation intention reminders can be (mis)used as reminder for the new behaviour.

The intention of the implementation intention reminder was to remind participants about rehearsing the sentence and thus to strengthen the connection between the existing habit and the new behaviour. However, some participants reported using the feature in a different and unintended way.

> "I knew that if it stayed in the Notification Center, there was a better chance that I would remember it when I looked at my phone again in the evening." - P2

> "It's enough for me to simply have the notification on my smartphone as a reminder that I still have to do this." - P5

Since the push notification contained the whole implementation intention in the form of *"After / Before I [Existing Habit], I will [New Behaviour]"*, participants could use it directly as a reminder for the new behaviour without performing the active rehearsal within the app.

Some participants also mentioned performing the active rehearsal only a few times in the beginning and then subsequently relying on the notifications only.

> "I've used it a few times only when I've opened it. So where in the app it would spell out the sentence while you're reading it. I thought it was nice because it gives you time to absorb the phrase to make it a little more conscious. But most of the time I've read it directly in the push notification." - P3

This coincides with another finding that relates to the impact of the reminders over time as described in the following paragraph.

F16: Impact of implementation intention reminders decreases over time.

> "And I looked at it at the beginning and then eventually knew it and then didn't need it. Especially in the first two days, I really tried to internalise that." - P7

> "I think in the beginning I read it and then I thought I have to do this tonight. And then at some point it was more, I click it to make it go away." - P14

> "And I also started to ignore the push notifications after the second, third time." - P11

This pattern of decreasing impact of notifications was reported commonly and is also reflected in the captured usage data of the functionality as shown on Figure 4.1. The usage of the reminders was also affected by another finding in relation to a flaw in the design of the push notification described as follows.

F17: Push notifications are not automatically perceived as interactable.

A number of participants reported that they did not understand that push notifications were clickable and that they could perform an active rehearsal of the implementation intention. While this functionality was explained during the onboarding, the design of the notification did not encourage the participants to interact with it.

> "I saw it almost everyday. But for a long time I did not understand, that you can click it." - P5

> "I just looked at it on the screen and then honestly forgot that I was supposed to click on it there." - P12

4.5 Habit Tracking & Sleep Diary

The app combined a sleep diary that captured sleep related metrics and tracking of the habits into a single functionality. Participants were tasked each morning to report within the app, whether they had performed the new behaviour on the evening before. A majority of participants filled out 3/4 or more of their daily sleep diaries (Mean = 76%, SD = 20.3%, Min = 31.3%, Max = 100%). This usage pattern is also shown on Figure 4.1 where each coloured box represents one sleep diary entry per participant per habit. Furthermore, it is reflected in the findings related to this functionality during the interviews as described in the following paragraphs.

F18: Next-day habit-tracking is feasible and perceived as low-effort intervention.

Many participants praised the sleep diary functionality and especially the next-day habit-tracking functionality and it was generally perceived as an intervention that requires low-effort.

> "I found that very good in this study. It wasn't a checkbox or a list that you have to go through on your smartphone in the evening." - P7

> "Basically, I found it pretty easy to integrate. It was so user friendly that it was no extra effort for me to briefly fill out my things in the morning. It doesn't require much attention during the day, which I found very convenient." - P11

F19: Next-day habit-tracking can foster reflection and act as additional reminder for new behaviour.

A common theme amongst the participants was that filling out the sleep diary with the habit-tracking on the next day helped them to reflect about what they did on the evening before and it also acted as an additional reminder to perform the new behaviour on the next day.

> "It also helps to remind you: Did I do it last night or not? Sometimes I did and sometimes I didn't. When I did not do it I also did not click the option in the app the next day in the morning." - P8

> "But also filling out the sleep diary every day. So that was also a reminder what I was doing at night." - P3

4.6 Impact

The following two findings are related to the impact that the use of the app had on the participants during the study.

F20: Usage of app can create and raise awareness about existing sleep hygiene routine.

Overall the app was successful in creating and raising the awareness of participants regarding their existing sleep hygiene routine and to identify areas for improvement.

> "The most rewarding part is that the app forced me to record my routines. If the app did not force me sometimes I could not realise that I have a sleeping routine. And I really have some good habits already and I can do some improvements actually. So the most rewarding part of the app is to let me know that recording habits is good for developing habits." - P8

Furthermore, it also helped participants to identify different routines and factors that might affect them.

> "I am certainly more aware of what kind of routine I have. I also wasn't aware that I have three different routines depending on whether it's a standard day, sports training or weekend. It makes sense in hindsight, but I wasn't aware of it before." - P1

F21: App did not increase smartphone usage in the evening or during the routine.

One design goal of the app was to not increase the time that participants spent on the smartphone during the evening. When asked whether using the app increased their smartphone usage in the evening (e.g., due to checking the routine in the app) participants unanimously reported that this was not the case and their smartphone usage was not affected by using the app.

> "I did not use it to check my routine. So regarding usage of smartphone I would not say that anything changed." - P6

4.7 Summary of Findings

The two weeks study and the analysis of the data collected within the app led to key findings that can be used to answer the three research questions. The findings are listed in Table 4.3 and are briefly summarised below.

> **RQ1:** How can the design of a smartphone application support habit-stacking?

In a first step, the app needs to support the analysis of the existing habits that are part of the sleep hygiene routine. However, they can be hard to identify due to their automatic nature. This process can be supported by providing a list of common habits based on which existing habits can be identified. Even if the habits are identified, the existing routine is affected by various factors: presence of people (e.g., visitors, spouses), deviation from usual schedule (e.g., staying up late due to work), planned evening activities (e.g., sports training), change of location or environment (e.g., sleeping at spouse's place) or lifestyle changes (e.g., change of job). Furthermore, the success of habit-stacking is greatly influenced by the stability of the existing routine and its habits, so identifying the most stable habits is an important first step.

In a second step, the app needs to facilitate combining existing stable habits that can act as cues with desired new behaviours. If the contexts of the existing habit and the new behaviour match (e.g., both are performed in the same room) this can facilitate the habit-stacking. Mediating factors of the success of the technique seem to be the complexity of the new behaviour (i.e., complex habits are harder to form), the mental state of participants and their motivation and knowledge about the benefits of the new behaviour and the availability of additional cues for the new behaviour. The design of the app should take these factors into consideration and try to alleviate their potential negative effect on the habit-formation process. Finally, in order to be successful habit-stacking needs to achieve two goals that the design of the app should address: (1) form a connection between the existing habit and the new behaviour (i.e., remind the participant to perform the new behaviour) and (2) lead to the actual performance of the new behaviour.

In a last step, the app needs to provide a way to track the progress with the new behaviour. Tracking the progress on the next day is a feasible approach and is perceived as low-efforts by participants. Additionally, it fosters reflection by forcing participants to think about the previous day and it can act as an additional reminder for performing the new behaviour on the same day.

> **RQ2:** How can implementation intentions support the process of habit-stacking?

Providing an interactive way to rehearse implementation intentions for the habit-stacking within the app is perceived as helpful. However, the effectiveness of the rehearsal is affected by how

attentive participants are while performing it. Additionally, actively visualising the process of performing the existing habit and the new behaviour in combination might improve the impact of the rehearsal. Reminders in the form of push notifications can be used to encourage the rehearsal of the implementation intention. However, the timing of the reminders needs to match the participants availability and mental state in order to be effective. A potential caveat to consider is that the reminders for the rehearsal can act as additional reminders for the new behaviour. Furthermore, the design of the push notifications should encourage users to interact with it, since they are not automatically perceived as interactable. Generally, the impact of the reminders seems to decline over time which the design of the functionality should address.

> **RQ3:** What is the impact of the smartphone application on supporting users in building better sleep hygiene routines?

The smartphone app can be used successfully to create and increase awareness about the existing sleep hygiene routine of participants while not increasing the usage of the smartphone during the routine itself. The functionality presented withing the app was generally perceived as helpful and half of the participants were able to perform the new behaviour as part of their existing daily sleep hygiene routine at least 50% of the time.

These findings pose some preliminary results for the potential impact of a smartphone app on the habit-formation process. The next chapter discusses the implications of these findings for the design recommendations identified in the existing literature and for the development of sleep hygiene apps.

#	Finding	RQ
Analysis of Existing Routine		
F1	Existing habits can be difficult to elicit due to their automatic nature.	RQ1
F2	Identifying existing habits can be facilitated by providing a list of common habits.	RQ1
F3	Stability of existing routine is affected by various factors.	RQ1
Habit-Stacking		
F4	Stability of existing habit affects success of habit-stacking.	RQ1
F5	Complexity of new behaviour affects success of habit-stacking.	RQ1
F6	Mental state and well-being of participants affects habit-stacking.	RQ1
F7	Motivation and knowledge about benefits of new behaviour mediate habit-stacking.	RQ1
F8	Availability of additional cues can benefit habit-stacking.	RQ1
F9	Matching contexts can facilitate habit-stacking.	RQ1
F10	Habit-stacking can be successful even if new behaviour is not performed.	RQ1
Implementation Intention Rehearsal		
F11	Implementation intentions and their rehearsal are perceived as helpful.	RQ2
F12	Impact of implementation intention rehearsal is mediated by active visualization and attention during rehearsal.	RQ2
Implementation Intention Reminder		
F13	Push notification reminders for the rehearsal of implementation intentions are perceived as helpful.	RQ2
F14	Effectiveness of implementation intention reminders is mediated by appropriateness of timing.	RQ2
F15	Implementation intention reminders can be (mis)used as reminder for the new behaviour.	RQ2
F16	Impact of implementation intention reminders decreases over time.	RQ2
F17	Push notifications are not automatically perceived as interactable.	RQ2
Habit-Tracking & Sleep Diary		
F18	Next-day habit-tracking is feasible and perceived as low-effort intervention.	RQ1
F19	Next-day habit-tracking can foster reflection and act as additional reminder for new behaviour.	RQ1
Impact		
F20	Usage of app can create and raise awareness about existing sleep hygiene routine.	RQ3
F21	App did not increase smartphone usage in the evening or during the routine.	RQ3

Table 4.3: Summary of key findings and their related research question.

Chapter 5

Discussion

The first section discusses the results of the study with regard to the design recommendations based on the existing literature (see Section 2.2.2). This is followed by a section discussing their implications for sleep hygiene apps. A final section outlines threats to validity and the limitations they pose for this work.

5.1 Design Recommendations

To answer the first two research questions, the following paragraphs discuss the findings from the user study with regard to the design recommendations identified in the existing literature. Where applicable, the existing recommendations have been augmented to include new aspects identified in this work. Additionally, important limitations are discussed for each design recommendation with relevant implications for further research.

DR1: Users should be able to specify their existing routine by including existing habits and the context they are performed in.

Previous work established the importance of allowing users to specify their existing routine [40]. In contrast to existing solutions, the Habstack app also allowed user to specify the context in which the existing habit is performed. This addition helped users to form habit-stacks with coherent contexts which can benefit habit-stacking (F9). Furthermore, specifying the context could allow the app to further guide the matching of existing habits with new behaviours in the future. For example, by ensuring that the context of both the existing habit and the new behaviour matches or by making appropriate suggestion once an existing habit is selected as a starting point for a new habit-stack.

In the solution designed for this work, users were not encouraged to update their existing routine to identify additional existing habits. Future work could explore how the process of analysing the existing routine could be performed iteratively. Since existing habits can be difficult to elicitate (F1), an iterative process in which users are asked on a regular basis (e.g., once every two weeks) to re-evaluate their existing routine could further increase the effectiveness of the approach.

DR2: Users should be provided with examples of 'good' cues to help them define their own.

This design recommendation based on existing work coincides with the findings of the study [67]. Providing a list with examples of common habits facilitates the identification of existing habits

as cues (F2). The app was limited in this regard by only providing three examples of existing habits. Future versions could include more examples based on the list of existing habits that were captured during the user study (see Table 4.1).

Future work could focus on the elicitation of common existing habits in various domains and examine to what degree existing routines overlap. To prevent participants from relying solely on the list, the app should also allow and encourage the addition of individual existing habits that might not be part of the list.

DR3: Users should be able to select and experiment with trigger events (i.e., existing habits) as cues to trigger the new behaviour.

This design recommendation based on existing work [66, 15] was the foundation for the habit-stacking functionality of the app. However, since the stability of the existing habit affects the success of the method (F4), users should also be able to switch trigger events if they prove to be unreliable.

Similar to the existing solutions, the Habstack app was limited in this regard and did not allow users to switch the existing habit. Future work could address this limitation and incorporate it as a suggestion during the habit-tracking part if the user missed the new behaviour repeatedly.

DR4: Users should be encouraged to identify and use additional cues.

The importance of leveraging additional cues on top of the existing habits has been identified before [68, 15] and confirmed during the user study (F8). Similar to existing solutions, the Habstack app did not encourage users to place additional cues in their environment. In addition to actively encouraging this behaviour, future versions could also incorporate suggestions for additional cues for each new behaviour (e.g., placing an empty glass of water next to the bed). This enhancement could also increase the effectiveness of the intervention by decreasing the dependence on the performance of the existing habit (F4).

More generally, future work could explore how the habit-stacking method can be augmented to include additional cues and how the identification and selection of these cues can be further supported using technology. Furthermore, by allowing users to capture these cues in the app, important information about what cues participants are selecting and how effective they are could be gathered.

DR5: Users should be able to form implementation intentions.

The feasibility of supporting the formation of implementation intentions using a smartphone app has been demonstrated before [69, 15, 70, 71]. The Habstack app successfully replicated these findings in the domain of sleep hygiene recommendations (F11). This demonstrates how implementation intentions could also play an important role for digital health interventions that focus on sleep related issues.

DR6: Users should be reminded about the implementation intentions before the selected trigger event occurs.

In accordance to existing solutions, the Habstack app also used push notifications to remind users about the implementation intention. While these reminders are perceived as helpful (F13) and can successfully increase the adherence to the new behaviour as demonstrated in existing work [70] they have the potential drawback that users might form a dependence on the reminders which can hinder the habit formation process [72].

Some existing solutions try to address this issue by sending notifications at a fixed time [70] or at a random time during the day [71]. However, since the effectiveness of the reminders depends

(a) Current design of reminders **(b) Proposal for improved design of reminders**

Figure 5.1: Design of push notification reminders for implementation intentions.

on the appropriateness of the timing (F14) both approaches have their limitations. To address this issue, the app allowed user to specify a custom time for the reminders but prevented users from using them as just-in-time reminders (by specifically disencouraging reminder times during the evening routine). While this approach is feasible for an app focusing on sleep hygiene routines, this might not be the case for apps in other domains. However, the approach of informing users about the drawbacks of using just-in-time reminders when specifying a custom reminder time could still be applicable.

Even with this limitation in place, users could still rely on the notifications as reminders for their new habit by deliberately not tapping the push notification, so it remained visible on their phone (F15). Since the content of the notification explicitly mentioned the new behaviour, it acted as a permanent reminder for the new habit (as shown in Figure 5.1a). Future work could address this issue by designing the content of the push notification without mentioning the new behaviour. An example of an improved design that addresses both issues is shown in Figure 5.1b. By explicitly encouraging the user to tap on the notification, this could also address the issue that some users did not perceive these reminders as interactable (F17). Future work could explore the feasibility and effectiveness of this approach in comparison to the existing design.

DR7: Implementation intention reminders should prompt the user to actively rehearse the intention.

Most existing solutions used push notifications to remind users about their implementation intentions [69, 70, 71]. This feature was also included in the app and was generally perceived as helpful (F13). In contrast to existing solutions, the Habstack app encouraged *active* rehearsal of implementation intentions as proposed by [70]. While there is some evidence indicating that visualisation (i.e., vividly imagining the performance of the existing habit and the new behaviour) can increase the effectiveness of implementation intentions [100] this has not yet been incorporated into existing solutions. By providing a distinct screen that showed a step-by-step animation of the sentence, the app aimed to encourage users to take a couple of seconds to rehearse the implementation intention. However, this method did not sufficiently encourage users to actively visualise the process of performing the habit (F12). This could be addressed in the future by explicitly prompting users to imagine the situation in which they will perform the new behaviour as part of the implementation intention rehearsal.

While watching the animation potentially requires more cognitive effort than just reading the sentence displayed in the push notification, there is still potential to design this functionality to include more active participation from the user. Participants of the study suggested that making the rehearsals more interactive (e.g., by requiring the user to type parts of the sentence) could also increase the engagement with the functionality and thus might be able to address the problem of diminishing impact of the reminders (F16):

> "It would be cool if it was a little more interactive. Or a bit different every time, instead of showing the same message every time. That would have triggered me to want to do something more or stay on it longer." - P13

Future work could explore how implementation intention rehearsals can be designed in a way that increases their effectiveness while preserving their unobtrusiveness.

DR8: Implementation intention reminders should be phased out in accordance with habit adherence to prevent dependency.

The phasing out of implementation intention reminders over time to prevent users from forming a dependency on the reminders has been proposed before [66]. However, it has not been included in existing solutions. Due to the short duration of the user study this functionality was also not incorporated into the Habstack app. However, since the impact of the reminders in the app decreased over time (F16) an alternative approach is proposed. The reminders should be regulated depending on the adherence of the user to the new behaviour. If the user repeatedly reports that the new behaviour was performed (i.e., by using the habit-tracking functionality) the app could suggest to disable the reminder. Conversely, if the user fails to complete the behaviour without the reminder, the app could suggest to re-activate it. If a user repeatedly fails to complete the new behaviour without the reminder it could mean that a dependency on it was formed and the app might propose additional support measures (e.g., placing additional cues or selecting a more appropriate existing habit as a cue).

Future research could examine how reminders can be phased out in relation to habit adherence. Additionally, future work could explore how the obtrusiveness of the reminders could be mediated based on the adherence (e.g., by relying on strong visual cues, sounds and vibration for low adherence).

DR9: Users should be asked later if the task was completed (i.e. no same-day habit tracking.

While habit-tracking is a common functionality amongst consumer facing apps, some authors argue that it might hinder the habit formation process by creating a dependency on the tracking technology [66]. Or in other words: users might stop to perform the behaviour if it is not tracked anymore. However, in the context of habit-stacking where the new behaviour is connected to an existing habit this might pose less of a problem. To prevent users from forming a dependency on the tracking functionality, Habstack used next-day habit-tracking in which users were asked on the next day whether they have performed the habit on the previous day. This successfully prevented users from using the app during their evening routine (F21) and was perceived as a feasible low-effort intervention by the users (F18).

Habit-tracking can also benefit habit formation by providing feedback and positive reinforcement [35]. This finding was replicated in the user study with claims by participants that the functionality helped them to reflect about their past behaviour (F19). Nevertheless, since some participants reported that the habit-tracking also acted as a reminder for the new behaviour, more research is needed to examine the possible formation of a dependency on this functionality.

The Habstack app was limited by only allowing users to specify whether the new behaviour was completed or not. Thus, the app only used the amount of repetitions to estimate the strength of the new habit. This approach is limited, since repetition does not necessarily mean that a habit is formed [101]. There are more sophisticated methods available to measure the *automaticity* of a habit [18, 101]. However, since these methods rely on scales with multiple items, they might lead to problems of engagement. Since users were also asked to fill out a sleep diary with multiple items, the habit-tracking was deliberately limited to one item per habit. Future work is required

to examine whether multi-item scales to measure habits strength prove to be feasible for consumer or patient oriented habit formation apps outside of a research context.

Another limitation of the single-item habit-tracking functionality is that in the context of habit-stacking there might be multiple reasons for omission of the new behaviour. Some participants reported, that they remembered to perform the habit (i.e., habit-stacking worked to some degree) but they did not perform the habit for other reasons (e.g., lack of motivation)(F10). Consequently, in order to measure the success of habit-stacking, the app should distinguish between not performing the habit because it has been forgotten or not performing it due to other reasons. Forgetting to perform the behaviour could imply that there is a misconfiguration of the habit-stack and its implementation intention reminder (e.g., wrong context of habits or wrong timing of reminder) to which the app could react accordingly.

5.2 Implications for Sleep Hygiene Apps

The following section discusses the findings in relation to the third research question, their potential implications for sleep hygiene apps as well as limitations and areas for future work.

Impact on Sleep Hygiene Routine

The Habstack app could be used successfully to create and increase awareness about the existing sleep hygiene routine of participants (F20). The functionality presented in the app was generally perceived as helpful and half of the participants were able to perform the new behaviour as part of their existing daily sleep hygiene routine at least 50% of the time. These findings suggest, that digital health interventions that target sleep related issues could benefit from incorporating support for habit formation techniques. While existing solutions educate users about sleep hygiene interventions (e.g., performing a breathing exercise) and include reminders to increase the adherence to the proposed sleep intervention [102, 80] they suffer from the same problem as existing habit-formation apps, where users potentially form a dependency on the reminders instead of forming a habit.

While the findings of this study support the short-term feasibility of the proposed solution, more research is needed to examine the long-term impact and feasibility of it. Given that a duration of two weeks is usually not sufficient for the formation of a habit [19] future work should examine how habit-formation techniques can affect existing sleep hygiene routines in the long run.

Another important limitation of this work and its impact on sleep hygiene routines is that it only focused on incorporating new behaviour and did not address removing unwanted habits from an existing routine. A common theme amongst participants was that they identified habits in their existing routine that they want to get rid off because they negatively affect their sleep.

> "Yes, so for example 'checking the mail' before I go to sleep, I feel that this is not good for my sleep." - P12

Future work should thus identify how the habit-formation techniques could be used to identify and address unwanted habits. This is especially important in the domain of sleep hygiene where a lot of habitual behaviour can negatively affect sleep (e.g., spending time in front of a screen before going to bed [46]).

Impact on Sleep Related Metrics

Whereas sleep diaries are commonly used amongst sleep related apps [12] they are not commonly used in combination with habit-tracking. Since both sleep diaries and habit-tracking are forms

of self-monitoring, their combination could be an effective tool to measure and improve sleep quality since it fosters reflection not only about how well participants sleep but also about what habits have been performed. To examine the feasibility of habit-tracking in combination with a standardised sleep diary, the app combined both aspects into a single functionality in which users reported whether they performed the habit on the previous evening and how well they slept. The intention of this functionality was to give users a way to reflect, how performing the new behaviour might have affected their sleep. While this was generally perceived as helpful, some participants reported that tracking sleep led to anxiety and stress which in turn negatively affected their sleep in the beginning of the study.

> "I did not sleep well the first night I started using the tool. Maybe because I just thought at the moment: 'Now I have to fall asleep as quickly as possible' and that backfired." - P7

Furthermore, the combination of features implied that users could expect to see an improvement in their sleep metrics after performing the new behaviour only a couple of times. For some participants this caused frustration and decreased their motivation when no benefits were perceived after a couple of repetitions.

> "There was no sign for me that [performing the new behaviour] changed anything. And I didn't have any feedback in the app: 'Hey well done' or 'You are on the right track' or 'Usually after 3 days / weeks the first effects show'. Nor had my subjectively perceived sleep quality changed." - P11

To address these issues, future work should set clear expectations with regard to the tracking of sleep related metrics (e.g., inform users that tracking the sleep could have a negative impact on their sleep in the beginning) and the amount of repetitions required before new behaviours might benefit their sleep. As proposed in the statement above, the app could indicate how long a sleep hygiene recommendation needs to be performed, before benefits will be perceivable.

While a sleep diary is a feasible method to self-monitor sleep, there are more accurate and less intrusive methods to track sleep (e.g., by relying on automated trackers using the smartphone [55]). While previous work has already demonstrated how automated tracking of sleep metrics can be used to experiment with different sleep hygiene recommendations [58], future work could explore, how automated tracking can be used in combination with habit-tracking while still preserving the benefits of daily reflection about sleep related metrics in combination with habit adherence.

Impact on Smartphone Usage

Past research has shown that smartphone usage can interfere with both sleep quality and quantity, especially when used before or after trying to fall asleep [45, 46]. To address this issue, the Habstack app was designed carefully to not introduce any dependency on the app during the evening routine. This was achieved by preventing users from placing reminders during the routine and by relying on next-day habit-tracking. Findings from the user study confirm, that the app did not increase smartphone usage during the evening routine (F21). This is an important consideration for the design of sleep related interventions that rely on habit-formation techniques.

Using the smartphone during the evening routine for other activities was a common theme amongst participants. When asked about the role of the smartphone in their existing routine, participants consistently reported that it plays a substantial role, especially since a number of existing habits revolve around it. Examples include: setting the alarm, watching videos, browsing social media, answering messages and e-mails or conducting phone calls.

> "It plays a big role. I'm actually on my smartphone all the time in the evening. [...] But I always have the smartphone with me. It's also my alarm clock. So it's always in close proximity as well." - P13

Future work should thus explore, how sleep interventions can reduce smartphone usage during the evening by addressing existing smartphone habits. Implementation intentions could be formed that include alternatives to the existing smartphone habits: *"Instead of [old smartphone habit], I will [new habit]"*. Alternatively, instead of completely replacing the smartphone, the app could also support the formation of implementation intentions using smartphone based behaviour that is less prone to impair sleep (e.g., *"Instead of browsing social media, I will re-watch a movie"*).

5.3 Threats to Validity and Limitations

The following sections outline both internal and external threats to validity and limitations that affect the results of this work. Additionally, suggestions on how to address these limitations in future work are presented.

Internal Validity

The short duration of the study (2 weeks) only allowed to test the feasibility of the proposed solution but not evaluate its long-term effect on sleep metrics. Since benefits of sleep hygiene recommendations are only perceivable once the behaviour is repeated over a longer period of time, the effect on sleep metrics could not be measured. However, since the sleep recommendations were selected based on the existing sleep science literature, their potential effect on sleep related metrics has been demonstrated before. Unfortunately, sleep hygiene recommendations are not universal (i.e., the same recommendation might affect individuals differently). Thus, measuring the effect on sleep also requires that participants first identify the recommendations that work for them individually. A prolonged study could make use of an AB phase design in which sleep metrics are measured in phase A as a baseline and an intervention is introduced in phase B to measure the effect of the new behaviours on sleep metrics or to compare the solution to alternatives (e.g., paper based habit diary or existing habit-formation app).

As the various factors impacting the existing routine of participants demonstrate (F3), testing the app in a more controlled setting or with an increased sample size could decrease the impact of external factors on the findings. However, since these factors affect habit-formation in real life, it is still important to consider them when designing habit-formation interventions.

Another aspect to consider is that participants' positive sentiment towards most functionality of the app could have been caused by novelty effects. This needs to be considered especially with regard to the sleep diary and habit-tracking functionality that require daily interaction. Furthermore, participants were aware that the adherence to the new habit is part of a study and that the researcher expected consistent habit repetition. Both of these issues could be addressed by a longer study in which these effects are expected to diminish after an initial period.

External Validity

The small number of participants for the user study (n = 14), their homogeneity with regard to age and the use of personal contacts for inviting participants might limit the generalisability of the results of this study. Further research is required to include participants from other demographics, especially with regard to other age groups because their usage of smartphones and evening routines might differ substantially.

Since the proposed solution focused on the domain of sleep hygiene, the generalisability to other domains might be limited. However, since the design recommendations have been elicited from the literature on habit-formation and the key findings are in line with findings by other authors, they could still guide future work in other domains. The only functionalities included specifically for sleep were the sleep hygiene recommendations and the sleep diary. Both of these features could be adapted to include recommendations for different domains and to allow tracking of relevant metrics in that domain. This is in line with the general willingness of participants to try the app in other domains (e.g., morning routine, work-place routine, detachment from work). Future work could thus generalise the proposed solution to include recommendations for other routines to examine, whether the design recommendations also apply in these domains and whether they lead to behaviour change.

Chapter 6

Conclusion

A wide range of smartphone applications have been developed to address sleep hygiene without supporting the required behaviour change. To overcome this limitation, this work demonstrated the feasibility of a smartphone app that integrates multiple habit formation techniques to support behaviour change in the domain of sleep hygiene. Design recommendations from the existing literature guided the implementation of the *Habstack* app which used habit-stacking, implementation intentions and habit-tracking to help users incorporate new sleep hygiene behaviour into their existing evening routine. It addressed limitations of existing work by preventing users from scheduling just-in-time reminders and by relying on next-day habit-tracking. The app was evaluated during a two week user study (n = 14) to evaluate the feasibility of the approach and to gain insights into users' experience with it. The findings of the study and the design and implementation of the app led to the following findings that answer the posed research questions:

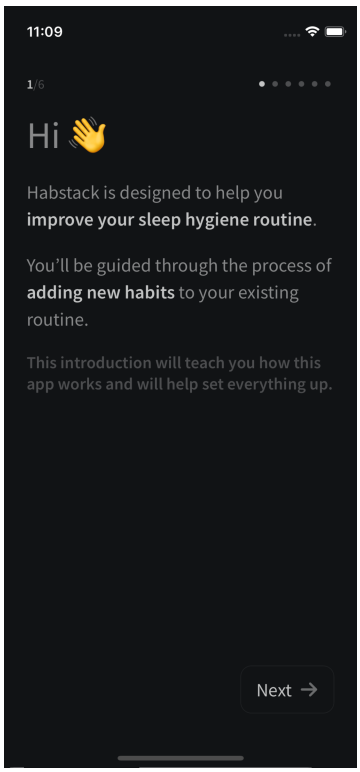
Habit-stacking can be supported by allowing the capturing of existing habits as cues for new behaviours and by providing recommendations for the new behaviour. Additionally, next-day habit-tracking can be used to foster reflection. The effectiveness could be improved by providing more examples of common existing habits, encouraging the formation of habit-stacks with matching contexts, and supporting the use of additional cues. The in-app rehearsal of implementation intentions and the corresponding reminders can help users to remember to perform the new behaviour. However, the reminder messages need to be designed carefully to avoid misuse as a direct reminder for the habit and to ensure that the intention is rehearsed before the existing habit is performed. The study revealed that the proposed solution was perceived as helpful, could create and raise awareness about the existing sleep hygiene routine, helped participants to incorporate new behaviour into their existing routine and did not increasing smartphone usage in the evening.

These findings provide preliminary evidence for the potential of using habit formation techniques to drive behaviour change in the domain of sleep hygiene. However, the short duration of the study, its small sample size and the homogeneity of the participants limit the validity of the findings and more work is needed to assess the long-term impact of the intervention. The current approach was also limited by only supporting users in adding new behaviour to their routine and not in altering or removing unwanted behaviour. Especially in the domain of sleep hygiene, this could greatly increase the impact of the intervention. Future research could thus explore how habit formation techniques could be used to alter existing behaviour (e.g., *Instead of [old habit], I will [new habit].*). While this work focused on sleep hygiene recommendations, the underlying approach could be transferred to other domains (e.g., morning routines or work-place routines) and the presented design and implementation of the app could be used as a foundation for more long-term research both in the domain of habit-formation and sleep hygiene.

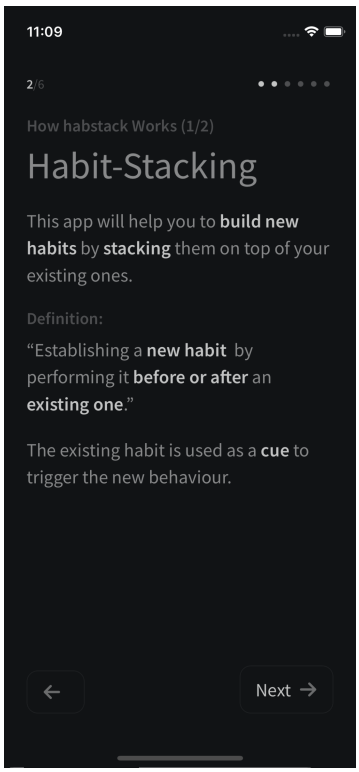
Appendix A

Habstack Application Images

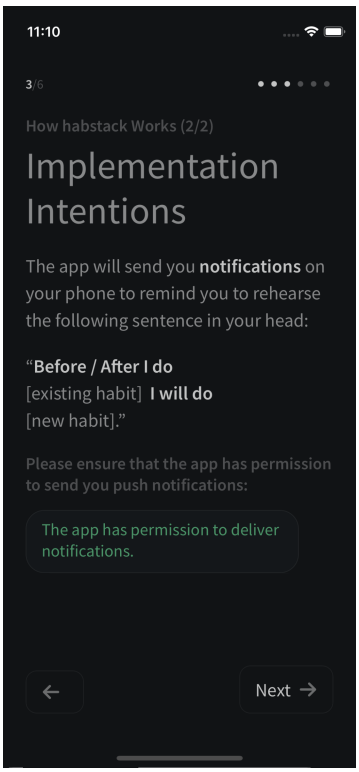
The following figures list all screens available in the Habstack app. The screens were recorded using an iPhone 12 mini but the app supported iPhones with different screen sizes as well.



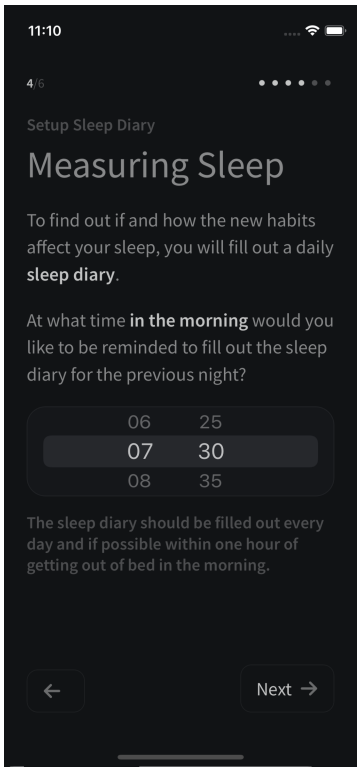
(a) Screen to welcome the user



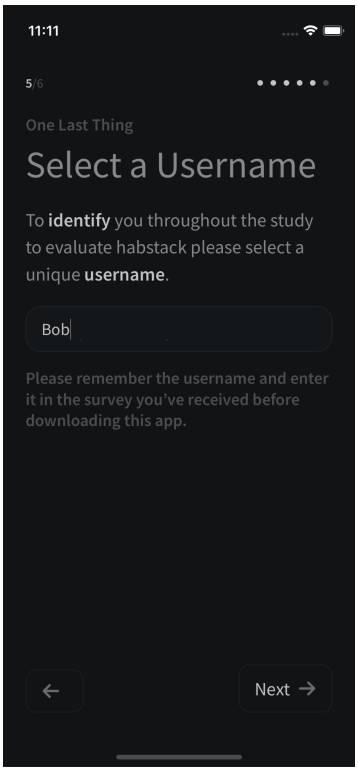
(b) Screen to introduce habit-stacking



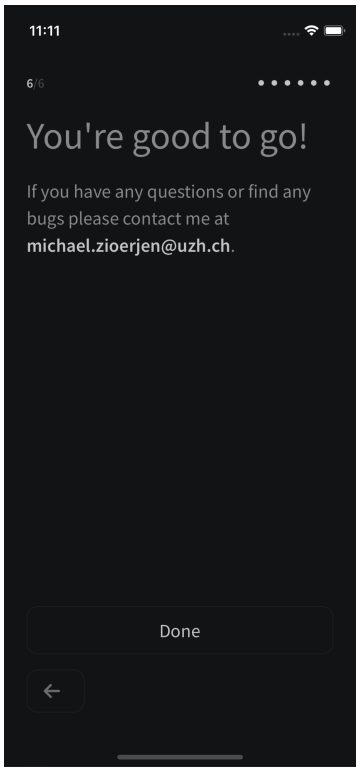
(c) Screen to introduce implementation intentions



(d) Screen to schedule sleep diary reminder

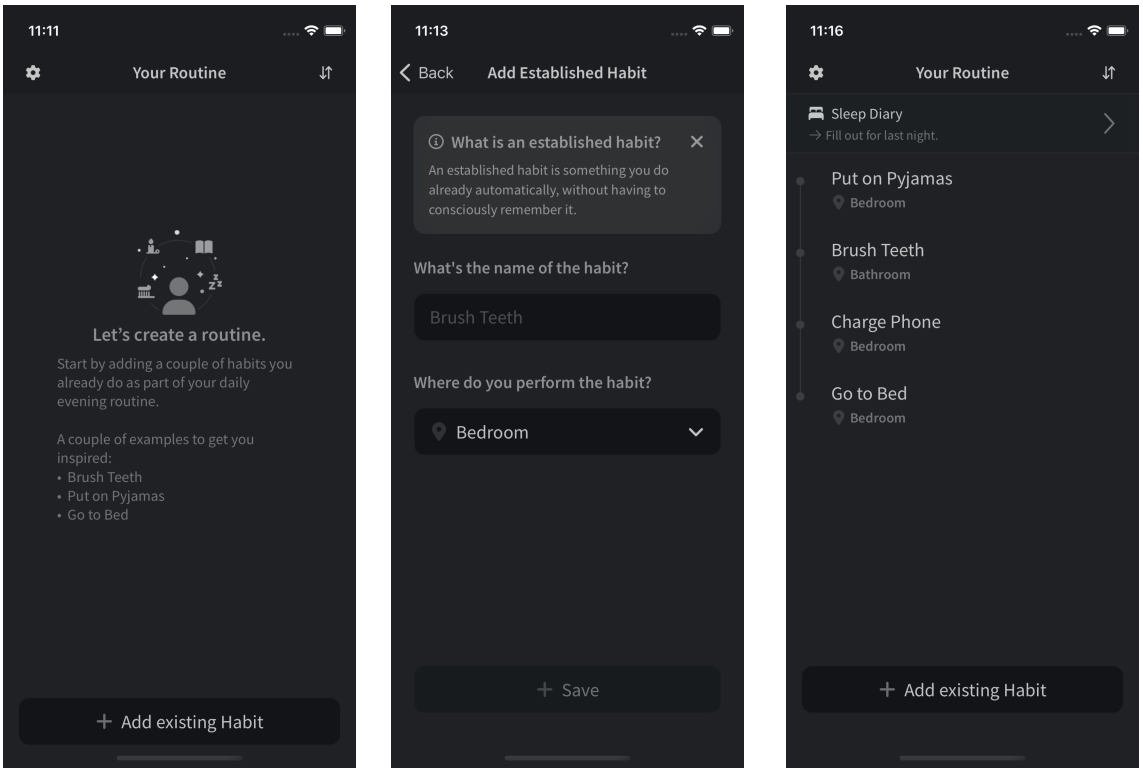


(e) Screen to select a username



(f) Final onboarding screen

Figure A.1: Initial onboarding screens to guide the setup of the app.

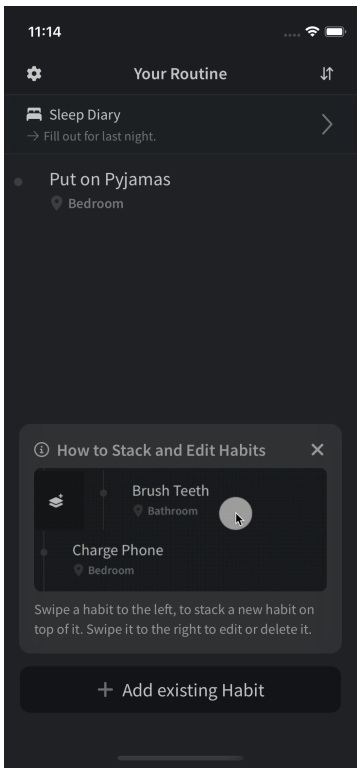


(a) Initial empty *Your Routine* screen

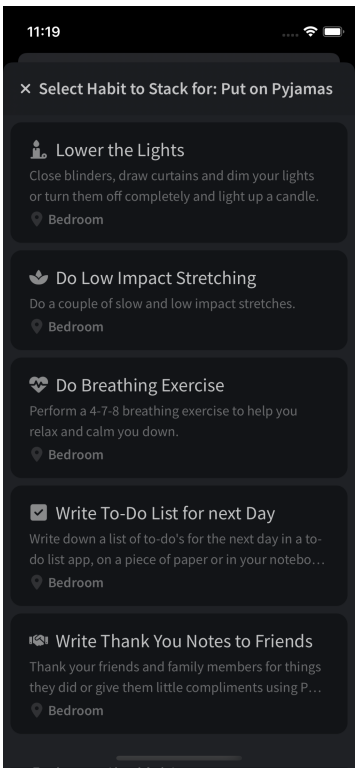
(b) Screen to add existing habit

(c) *Your Routine* screen after adding existing habits

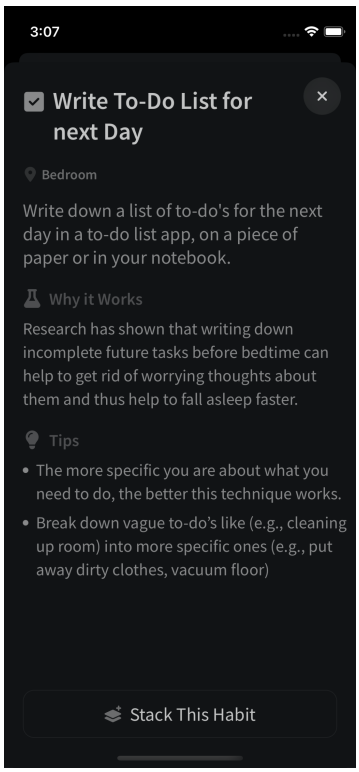
Figure A.2: Screens to analyse the existing routine.



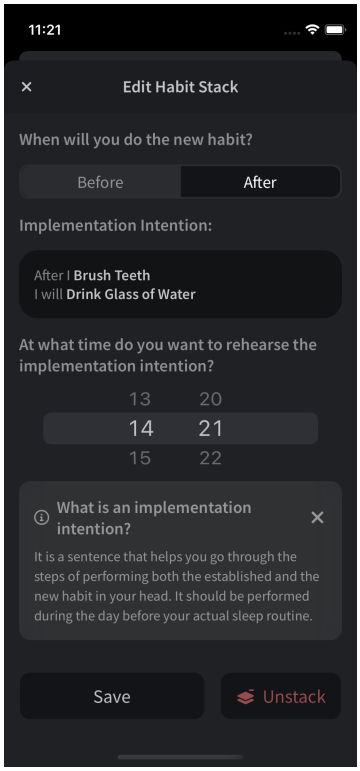
(a) *Your Routine* screen with explanation on how to stack and edit habits



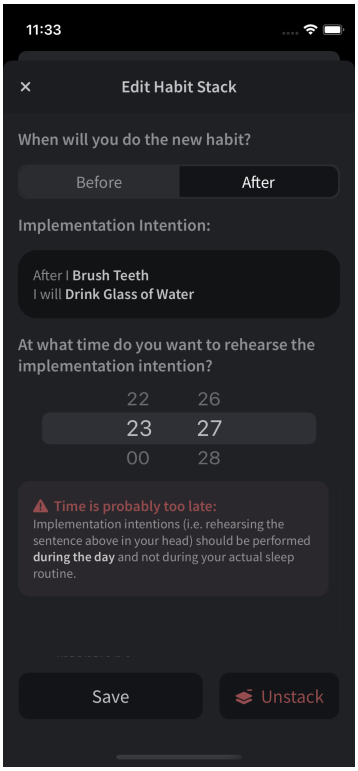
(b) Screen with sleep hygiene recommendations



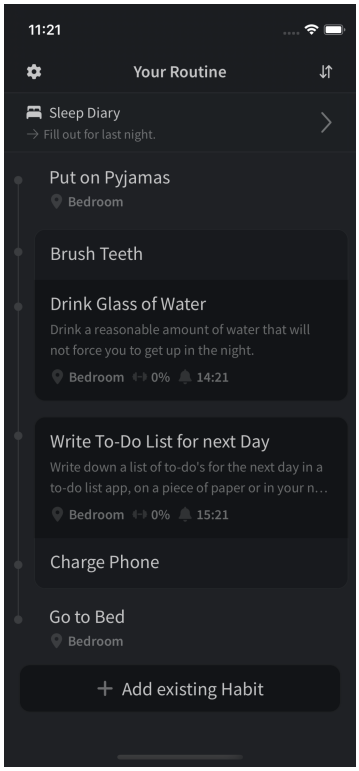
(c) Detail screen for a recommendation



(d) Screen to configure a habit-stack

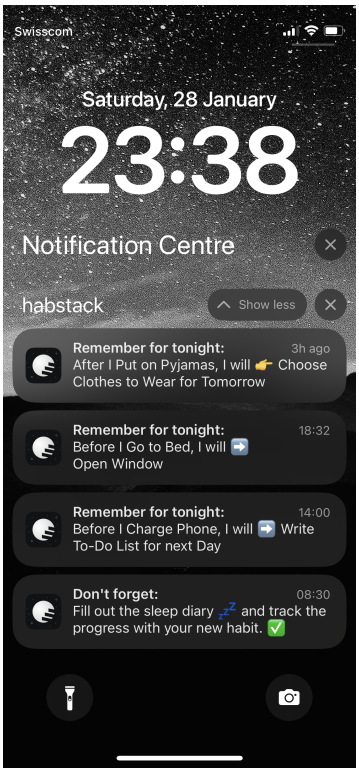


(e) Screen with warning message for inappropriate reminder time

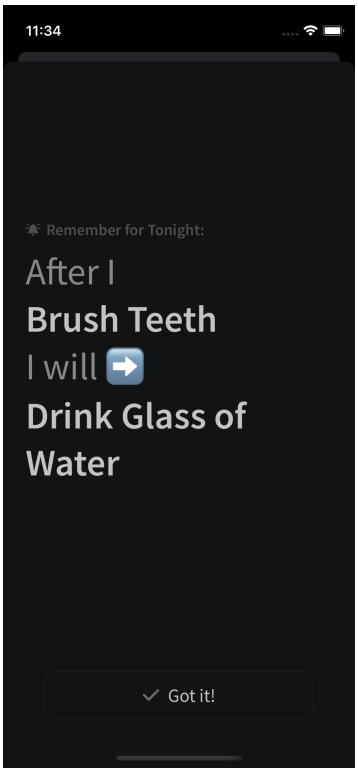


(f) *Your Routine* screen after forming two habit-stacks

Figure A.3: Screens to form habit-stacks.

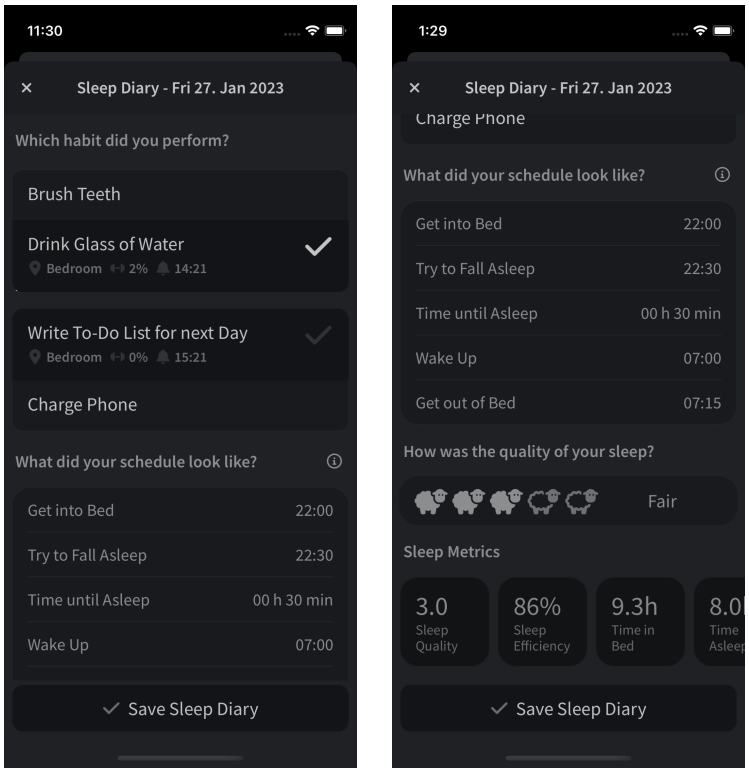


(a) Push notification reminders for the rehearsal



(b) Screen to rehearse implementation intention

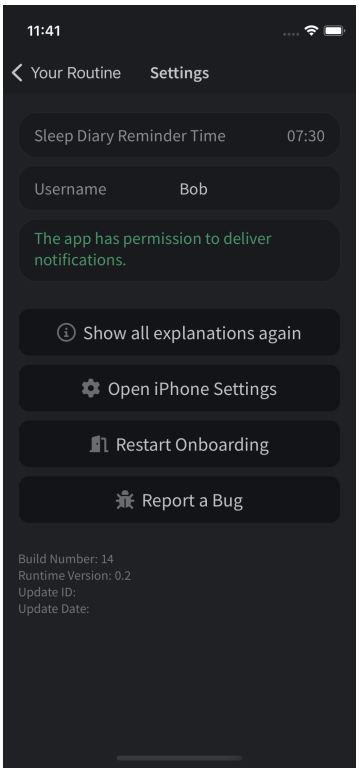
Figure A.4: Implementation intention reminders and rehearsal screen.



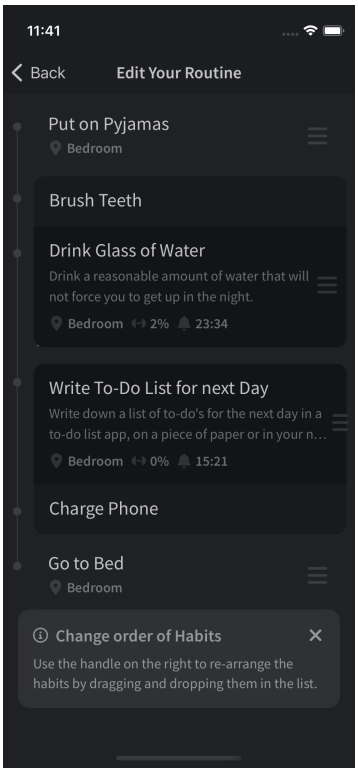
(a) Habit-tracking part (top)

(b) Sleep diary part with metrics (bottom)

Figure A.5: Screen for habit-tracking and sleep diary.



(a) Screen to change app settings



(b) Screen to change order of habits and habit-stacks

Figure A.6: Additional screens to change order of habits and change app settings

Appendix B

Authorisation of Research Project

The study conducted in this thesis was authorised by the Human Subjects Committee of the Faculty of Economics, Business Administration and Information Technology.

University of Zurich[UZH]

Human Subjects Committee of the
Faculty of Economics, Business Administration,
and Information Technology

Department of Economics

University of Zurich
Blümlisalpstrasse 10
CH-8006 Zurich
Phone +41 (0)44 634 37 01
Fax +41 (0)44 634 49 07
www.econ.uzh.ch

Prof. Dr. Michel Maréchal
Member of Human Subjects Committee
+41 44 63 45191
michel.marechal@econ.uzh.ch

Zurich, December 1, 2022

Authorization of research project "Analysing and Fostering Better Sleep Hygiene Routines using a Smartphone Application" (OEC IRB # 2022-091)

To whom it may concern,

The Human Subjects Committee of the Faculty of Economics, Business Administration and Information Technology at the University of Zurich authorizes the research described in Thomas Fritz's research proposal "Analysing and Fostering Better Sleep Hygiene Routines using a Smartphone Application" (OEC IRB # 2022-091).

Specifically, we have reviewed the information regarding the procedures and protocols that will be implemented to conduct the experiments involving human subjects. We confirm that they comply with all applicable regulations.

We therefore approve the planned research outlined in the proposal.

Yours sincerely,

Prof. Dr. Michel Maréchal
Member of the Human Subjects Committee
Head of Human Subjects Committee

Appendix C

Informed Consent Form

The following pages display the consent form that participants were given. All participants gave their explicit consent by signing the form before participating in the study.

Universität Zürich[UZH]

Human Aspects of Software Engineering Lab
University of Zürich
Department of Informatics
Binzmühlestrasse 14
CH-8050 Zürich

Contact: Michael Ziörjen (michael.zioerjen@uzh.ch)

Informed Consent Form
Analysing and Fostering Better Sleep Hygiene Routines using a Smartphone Application

Principal Investigators
Prof. Dr. Thomas Fritz, Department of Informatics, University of Zurich (fritz@ifi.uzh.ch)
Supervision
Anastasia Ruvimova, PhD Student, University of Zurich (ruvimova@ifi.uzh.ch)
Kevin Chow, PhD Student, University of British Columbia (kchowk@cs.ubc.ca)
Students / Developers
Michael Ziörjen, MSc Student, University of Zurich (michael.zioerjen@uzh.ch)

Please read the following instructions carefully and give your written consent in the fields marked red.

I. Purpose
The goal of this study is to evaluate the use of a new software called "habstack" and its effect on sleep hygiene routines. Habstack aims to help users to analyze their existing sleep hygiene routine and incorporate new behavior using the "habit-stacking" technique.

II. Study Procedure
The study spans across two weeks (**14 days**) during which you will interact with the app on a daily basis for a couple of minutes (**2-5 mins**). The app will send you **notifications** during the day to remind you of rehearsing the implementation intentions. Furthermore, you will fill out a **daily sleep diary** to track the impact of the new habits on your sleep.

What happens if you miss a day?
It is okay if you miss single days or if you do not use the application on weekends. However, for the sleep and habit data to be accurate you are expected to fill out the sleep diary for at least a couple of consecutive days.

At the end of the study, a final interview (**30-45 mins**) will be conducted. The steps are described in detail below:

1. **Preliminary Survey (5-10 min)**
   As a first step you will be asked to fill in a preliminary survey on demographics and your existing sleep hygiene routine.

2. **Download and Installation of the App (5 min)**
   Afterwards, you will be asked to download and install the habstack app on your smartphone. As a first step, you need to install Apple's official Testflight app that is used to test and distribute the app. As a second step you will install the habstack app.

   The habstack app is currently only available for iOS (Version 13+).

Universität Zürich[UZH]

Department of Informatics

3. **Study (2 weeks, 2-5 mins daily)**
   During a period of two weeks, you will use the habstack app. In the beginning, the app will guide you through the process of analyzing your existing routine and incorporating new habits into it (5 mins). After the initial setup, the app will send you daily reminders to perform "implementation intentions" during which you mentally rehearse the new habit (30s). Furthermore, you are asked to fill out a daily sleep diary to measure the effect of the new habit on a number of sleep related metrics (2 mins).

4. **Final Interview (30 - 45 mins)**
   To wrap up the study, we want to examine your learnings, experience, and suggestions to improve habstack in the future during an interview. The interview will take no longer than 30-45 minutes and will be conducted online using a video conferencing tool of your choice (e.g., Skype, Zoom, Google Hangout, etc.) During the interview you will be asked questions about your experience with the app and how it affected your sleep hygiene routine.

III. Benefits and Risks

By participating in this study, you will learn more about your existing sleep hygiene routine, recommendations for habits that could positively affect your sleep and how to build new habits based on the "habit stacking" technique supported by "implementation intentions".

The main risk is the loss of time required to participate in the study. The total amount of time required to participate in the study is assumed to be 2-4 hours during the 2 weeks. This risk is mitigated by allowing you to determine a suitable time for the study participation as well as the final interview. Furthermore, you are free to withdraw from participation at any point during the study, without the need to provide a reason.

While all the sleep habit recommendations have been sourced from the existing sleep science literature, they should not be considered as medical advice. If you are suffering from sleep related health issues or have been diagnosed with a sleep related condition (e.g. insomnia) then you should seek advice from a medical professional before using the app or refrain from participating in this study. In the unlikely event that you encounter any negative effects on your sleep related behavior caused by using the app or by participating in this study, please inform the research team immediately and refrain from using the app.

IV. Personal Information

During the study, personal information about you such as your name, email address, gender, age and current job title will be collected. Furthermore, subjective sleep related metrics are captured using a sleep diary. For this research, only your anonymized data will be used and no identifying information will ever be shared outside of the research group and the confines of this study without your explicit permission. All data collected will be saved in password-protected storages. The identifiable data will only be stored for 1 year before either being de-identified or deleted.

V. Data, Storage & Confidentiality

All the data collected by the habstack app is stored in a password-protected database located in Europe. The habstack app uses SSL/TLS encryption to protect the confidentiality of the data during transmission.

The survey data (preliminary survey and final questionnaire) will be stored in the online survey tool. The final interview **audio recording** will be transcribed by one of the researchers. After the transcriptions, the audio recording will be deleted.

Universität Zürich[UZH]

Department of Informatics

All data will be saved on the researchers' password-protected devices. You will be identified by pseudonyms in any internal or academic research publication or presentation. Your data will be used and seen only by researchers directly involved with this project. The anonymized, non-identifiable data will be stored for five years, after which it will be permanently deleted.

VI. Uses of the Study Data

The results of this study will potentially appear in both internal and external academic research presentations and publications, such as academic journals and conference proceedings.

VII. Contact for Information about the Study

If you have any questions or desire further information with respect to the study, you may contact the research team: Michael Ziörjen (michael.zioerjen@uzh.ch), Anastasia Ruvimova (ruvimova@ifi.uzh.ch) or Kevin Chow(kchowk@cs.ubc.ca).

VIII. Consent for extended Data Uses

With your explicit consent, you can allow further people access to the data for educational purposes or the application of further scientific methods. Please sign with your initials next to the usage options you agree with:

☐ I allow the use of my anonymized data for educational purposes within the scope of classes/lectures offered at the University of Zurich.

☐ I allow the use of my anonymized data by external researchers to apply scientific methods.

IX. Consent for Study Participation

Your participation in this study is entirely voluntary. You are free to withdraw your participation at any point during the study, without needing to provide any reason. Any information you contribute up to your withdrawal will be retained and used in this study unless you request otherwise.

With your signature on this form, you confirm the following statements:

- An investigator explained the study and the listed conditions to me. I had the opportunity to ask questions. I understood the answers and accepted them.
- I am at least 18 years old.
- I had enough time to make the decision to participate and I agree to the participation.

In no way does this waive your legal rights or release the investigators or involved institutions from their legal or professional responsibilities.

☐ I allow the the collection of **anonymized in-app data** during the study and the **recording of audio** during the final interview.

_____

Participant's name

_____ _____

Location, Date **Participant's signature**

Appendix D

User Study Interview Script

Interview Guide Habstack

0. Before Interview

- ☐ Test recording (Audio on MacBook Pro)
- ☐ Prepare / Setup backup audio recording (using iPhone)
- ☐ Check consent form submission: if not, then prepare it beforehand
- ☐ Fill out [personalized content] in the interview guide
- ☐ Download backup of data from Firebase

1. Introduction (2-3 min)

- Build rapport & Introduction: Master thesis at the University of Zurich: Evaluation to gather feedback on app and its effect on sleep routine
- Establish common ground for talking about experiences, ensure that participants don't feel like being tested -> app is still an early prototype, there are no right / wrong answers, both positive and negative comments will be equally valuable for improving the app.
- Explain process of Interview and est. duration
- Mention that interview is being recorded and confidential

2. Feedback & Evaluation (30-40 min)

2.1 Warm-Up

- You've started using habstack on the [Day] of [Month] and used it for the last 14 days, correct?
- What was your overall experience with the app? [RQ1, RQ2, RQ3]

2.2 Existing Routine / Established Habits

- You've added [established habit] and [other established habit] as existing habits in your routine. Why did you pick those two/three? [RQ1]
- Does your evening routine consist of more habits? Why did you not add them? [RQ1]
- What role does the smartphone play in your evening routine?
    - Is there a distinct moment where you turn off the phone or put it away?
- What changed during the study? Did you "check" on your routine or did you solely rely on the notifications i.e. implementation intentions? [RQ1, RQ2]

2.3 Habit Stacking & Implementation Intentions

Per Stacked Habit:

- How do you feel about your progress with developing this habit? [RQ1]
- You've stacked [new habit] on top of [established habit].
    - Why did you choose the new habit?
    - Why did you select the established one? [RQ1]
- Why did you decide to do it [before / after]? [RQ1]
- During the study you performed the new habit [amount] times out of [max. amount = days in study]. During these instances, what was your experience with performing the new and the old habit in combination? [RQ1]
    - Do you feel like the data collected in the app reflects how often you've performed the new app in real life? [RQ1]
- Can you recall the last time you've performed the new habit? How did that go? [RQ1]
    - Did you make use of the explanation / tips provided in the app [RQ1]
- Can you recall an instance where you did not perform the habit? What went wrong? [RQ1]
- You've received notifications and performed implementation intentions. What was your experience with this functionality? [RQ2]
    - [Based on usage pattern] Can you explain why you've used the functionality in this way (e.g. stopped using it in the second week)?
    - How did you rehearse the sentence displayed on your phone? [RQ2]
    - Was the amount of notifications appropriate or would you have preferred fewer or more notifications i.e. times to rehearse the implementation intention? [RQ2]
- Did you use any other cues / reminders to perform the new habit? If so, what did you use? [RQ1]
- What effect did rehearsing the implementation intention have on performing the new habit in the evening? [RQ3]
- Do you plan on continuing working on the habits [RQ3]

Changes / Edits:

- You've added / removed [new habit]. Can you tell me a bit more about your thought process behind this? [RQ1]
- You've changed the notification time from [X] to [Y]. Why did you make that change? [RQ2]

2.4 Sleep Routine

- You've filled out sleep diary entries. What was your experience with that functionality? [pattern / amount of sleep diary entries]
- What impact did using the application have on your sleep routine if you think about now vs. before participating in the study? [RQ3]
- What effect, if there was any, did performing the new habits have on your sleep? And on your evening routine? [RQ3]

- What effect did the act of tracking your sleep have? How did you feel about knowing that you will need to track it in the next morning?
- In the initial survey you've mentioned that you are [not] aware of how habits in your routine can positively or negatively affect your sleep. Would you say that anything changed after using habstack during the study? [RQ3]

2.5 General Feedback

- What was the most rewarding part about using habstack?
- What was the most frustrating part about using habstack?
- Would you consider using it in the future? Why / why not?
- What changes might need to be made in order for you to use it in the future?
- Would you be interested in trying the app for other non-sleep related aspects of your life?
- Is there anything else you would like to share?

3. Debrief (5 min)

- Turn off recording
- Ask if they would like to add something off-the-record
- Explain how to remove app from phone and delete all data
- Thank you

4. After Interview

- Summarize and perform "brain dump": Write down most important findings
- Save recording (P_[ID]_Interview_MM_DD_YY) where ID is the participant ID

Bibliography

[1] W. Durant, *The Story of Philosophy*, 2nd. New York: Garden City Publishing Co., Inc., Dec. 1926.

[2] D. Léger, B. Poursain, D. Neubauer, and M. Uchiyama, "An international survey of sleeping problems in the general population," *Current Medical Research and Opinion*, vol. 24, no. 1, pp. 307–317, Jan. 2008.

[3] S. Stringhini *et al.*, "Association of socioeconomic status with sleep disturbances in the Swiss population-based CoLaus study," *Sleep Medicine*, vol. 16, no. 4, pp. 469–476, Apr. 2015.

[4] M. M. Ohayon, "Epidemiology of insomnia: What we know and what we still need to learn," *Sleep Medicine Reviews*, vol. 6, no. 2, pp. 97–111, May 2002.

[5] M. Irwin, J. McClintick, C. Costlow, M. Fortner, J. White, and J. C. Gillin, "Partial night sleep deprivation reduces natural killer and cellular immune responses in humans." *The Journal of the Federation of American Societies for Experimental Biology*, vol. 10, no. 5, p. 11, 1996.

[6] J. S. Durmer and D. F. Dinges, "Neurocognitive Consequences of Sleep Deprivation," *Seminars in Neurology*, vol. 25, no. 1, p. 13, 2005.

[7] K. T. Baum, A. Desai, J. Field, L. E. Miller, J. Rausch, and D. W. Beebe, "Sleep restriction worsens mood and emotion regulation in adolescents," *Journal of Child Psychology and Psychiatry*, vol. 55, no. 2, pp. 180–190, Feb. 2014.

[8] D. F. Kripke, L. Garfinkel, D. L. Wingard, M. R. Klauber, and M. R. Marler, "Mortality Associated With Sleep Duration and Insomnia," *Archives of General Psychiatry*, vol. 59, no. 2, p. 131, Feb. 2002.

[9] L. A. Irish, C. E. Kline, H. E. Gunn, D. J. Buysse, and M. H. Hall, "The role of sleep hygiene in promoting public health: A review of empirical evidence," *Sleep Medicine Reviews*, vol. 22, pp. 23–36, Aug. 2015.

[10] P. J. Hauri, "Sleep Hygiene, Relaxation Therapy, and Cognitive Interventions," in *Case Studies in Insomnia*, P. J. Hauri, Ed., Boston, MA: Springer US, 1991, pp. 65–84.

[11] D. S. Grigsby-Toussaint, J. C. Shin, D. M. Reeves, A. Beattie, E. Auguste, and G. Jean-Louis, "Sleep apps and behavioral constructs: A content analysis," *Preventive Medicine Reports*, vol. 6, pp. 126–129, Jun. 2017.

[12] B. Erten Uyumaz, L. Feijs, and J. Hu, "A Review of Digital Cognitive Behavioral Therapy for Insomnia (CBT-I Apps): Are They Designed for Engagement?" *International Journal of Environmental Research and Public Health*, vol. 18, no. 6, p. 2929, Mar. 2021.

[13] I. Anderson *et al.*, "Shakra: Tracking and Sharing Daily Activity Levels with Unaugmented Mobile Phones," *Mobile Networks and Applications*, vol. 12, no. 2-3, pp. 185–199, Jun. 2007.

[14] T. Denning *et al.*, "BALANCE: Towards a usable pervasive wellness application with accurate activity inference," *Proceedings of the 10th workshop on Mobile Computing Systems and Applications*, pp. 1–6, Feb. 2009.

[15] C. Pinder, J. Vermeulen, B. R. Cowan, and R. Beale, "Digital Behaviour Change Interventions to Break and Form Habits," *ACM Transactions on Computer-Human Interaction*, vol. 25, no. 3, pp. 1–66, Jun. 2018.

[16] B. Verplanken and H. Aarts, "Habit, Attitude, and Planned Behaviour: Is Habit an Empty Construct or an Interesting Case of Goal-directed Automaticity?" *European Review of Social Psychology*, vol. 10, no. 1, pp. 101–134, Jan. 1999.

[17] Merriam-Webster. "Definition of ROUTINE." (No Date), [Online]. Available: `https://www.merriam-webster.com/dictionary/routine` (visited on 01/24/2023).

[18] B. Verplanken and S. Orbell, "Reflections on Past Behavior: A Self-Report Index of Habit Strength [1]," *Journal of Applied Social Psychology*, vol. 33, no. 6, pp. 1313–1330, Jun. 2003.

[19] P. Lally, C. H. M. van Jaarsveld, H. W. W. Potts, and J. Wardle, "How are habits formed: Modelling habit formation in the real world," *European Journal of Social Psychology*, vol. 40, no. 6, pp. 998–1009, Oct. 2010.

[20] M. Fournier *et al.*, "Effects of circadian cortisol on the development of a health habit." *Health Psychology*, vol. 36, no. 11, pp. 1059–1064, Nov. 2017.

[21] M. Stojanovic, A. Grund, and S. Fries, "App-Based Habit Building Reduces Motivational Impairments During Studying – An Event Sampling Study," *Frontiers in Psychology*, vol. 11, p. 167, Feb. 2020.

[22] J. Keller, D. Kwasnicka, P. Klaiber, L. Sichert, P. Lally, and L. Fleig, "Habit formation following routine-based versus time-based cue planning: A randomized controlled trial," *British Journal of Health Psychology*, vol. 26, no. 3, pp. 807–824, Sep. 2021.

[23] A. van der Weiden, J. Benjamins, M. Gillebaart, J. F. Ybema, and D. de Ridder, "How to Form Good Habits? A Longitudinal Field Study on the Role of Self-Control in Habit Formation," *Frontiers in Psychology*, vol. 11, p. 560, Mar. 2020.

[24] M. J. Louro, R. Pieters, and M. Zeelenberg, "Dynamics of multiple-goal pursuit." *Journal of Personality and Social Psychology*, vol. 93, no. 2, pp. 174–193, Aug. 2007.

[25] P. M. Gollwitzer, "Goal Achievement: The Role of Intentions," *European Review of Social Psychology*, vol. 4, no. 1, pp. 141–185, 1993.

[26] P. M. Gollwitzer, "Implementation Intentions," *American Psychologist*, p. 11, 1999.

[27] P. M. Gollwitzer and P. Sheeran, "Implementation Intentions and Goal Achievement: A Meta-analysis of Effects and Processes," in *Advances in Experimental Social Psychology*, vol. 38, Elsevier, 2006, pp. 69–119.

[28] M. A. Adriaanse, C. D. Vinkers, D. T. De Ridder, J. J. Hox, and J. B. De Wit, "Do implementation intentions help to eat a healthy diet? A systematic review and meta-analysis of the empirical evidence," *Appetite*, vol. 56, no. 1, pp. 183–193, Feb. 2011.

[29] A. Bélanger-Gravel, G. Godin, and S. Amireault, "A meta-analytic review of the effect of implementation intentions on physical activity," *Health Psychology Review*, vol. 7, no. 1, pp. 23–54, Mar. 2013.

[30] L. McWilliams, S. Bellhouse, J. Yorke, K. Lloyd, and C. J. Armitage, "Beyond "planning": A meta-analysis of implementation intentions to support smoking cessation." *Health Psychology*, vol. 38, no. 12, pp. 1059–1068, Dec. 2019.

[31] S. Orbell and B. Verplanken, "The automatic component of habit in health behavior: Habit as cue-contingent automaticity." *Health Psychology*, vol. 29, no. 4, pp. 374–383, 2010.

[32] P. M. Gollwitzer and B. Schaal, "Metacognition in Action: The Importance of Implementation Intentions," *Personality and Social Psychology Review*, vol. 2, no. 2, pp. 124–136, May 1998.

[33] T. L. Webb and P. Sheeran, "Identifying good opportunities to act: Implementation intentions and cue discrimination," *European Journal of Social Psychology*, vol. 34, no. 4, pp. 407–419, Jul. 2004.

[34] M. A. McDaniel and G. O. Einstein, "Strategic and automatic processes in prospective memory retrieval: A multiprocess framework," *Applied Cognitive Psychology*, vol. 14, no. 7, Jan. 2000.

[35] P. Lally and B. Gardner, "Promoting habit formation," *Health Psychology Review*, vol. 7, no. sup1, S137–S158, May 2013.

[36] J. Clear. "How to Build New Habits by Taking Advantage of Old Ones." (Aug. 2014), [Online]. Available: `https://jamesclear.com/habit-stacking` (visited on 01/24/2023).

[37] J. Clear, *Atomic habits: tiny changes, remarkable results : an easy & proven way to build good habits & break bad ones*. New York: Avery, 2018.

[38] B. J. Fogg, *Tiny habits: the small changes that change everything*. Boston: Houghton Mifflin Harcourt, 2019.

[39] P. Lally, J. Wardle, and B. Gardner, "Experiences of habit formation: A qualitative study," *Psychology, Health & Medicine*, vol. 16, no. 4, pp. 484–489, Aug. 2011.

[40] K. Stawarz, A. L. Cox, and A. Blandford, "Don't forget your pill!: Designing effective medication reminder apps that support users' daily routines," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, Toronto Ontario Canada: ACM, Apr. 2014, pp. 2269–2278.

[41] G. Judah, B. Gardner, and R. Aunger, "Forming a flossing habit: An exploratory study of the psychological determinants of habit formation," *British Journal of Health Psychology*, vol. 18, no. 2, pp. 338–353, May 2013.

[42] J. S. Labrecque, W. Wood, D. T. Neal, and N. Harrington, "Habit slips: When consumers unintentionally resist new products," *Journal of the Academy of Marketing Science*, vol. 45, no. 1, pp. 119–133, Jan. 2017.

[43] A. Bandura, "Social Cognitive Theory: An Agentic Perspective," p. 28, 2000.

[44] S. Michie, C. Abraham, C. Whittington, J. McAteer, and S. Gupta, "Effective techniques in healthy eating and physical activity interventions: A meta-regression." *Health Psychology*, vol. 28, no. 6, pp. 690–701, 2009.

[45] S. K. Adams, J. F. Daly, and D. N. Williford, "Adolescent Sleep and Cellular Phone Use: Recent Trends and Implications for Research," *Health Services Insights*, vol. 6, HSI.S11083, Jan. 2013.

[46] C. Cajochen *et al.*, "Evening exposure to a light-emitting diodes (LED)-backlit computer screen affects circadian physiology and cognitive performance," *Journal of Applied Physiology*, vol. 110, no. 5, pp. 1432–1438, May 2011.

[47] G. Tosini, I. Ferguson, and K. Tsubota, "Effects of blue light on the circadian system and eye physiology," *Molecular Vision*, p. 12, 2016.

[48] A.-M. Chang, D. Aeschbach, J. F. Duffy, and C. A. Czeisler, "Evening use of light-emitting eReaders negatively affects sleep, circadian timing, and next-morning alertness," *Proceedings of the National Academy of Sciences*, vol. 112, no. 4, pp. 1232–1237, Jan. 2015.

[49] M. Al Kazhali, M. Shahwan, N. Hassan, and A. A. Jairoun, "Social media use is linked to poor sleep quality: The opportunities and challenges to support evidence-informed policymaking in the UAE," *Journal of Public Health*, fdab372, Oct. 2021.

[50] X. L. X. Run Zhi Zhu, "The Influence of Social Media on Sleep Quality: A Study of Undergraduate Students in Chongqing, China," *Journal of Nursing & Care*, vol. 04, no. 03, 2015.

[51] G. Hisler, J. M. Twenge, and Z. Krizan, "Associations between screen time and short sleep duration among adolescents varies by media type: Evidence from a cohort study," *Sleep Medicine*, vol. 66, pp. 92–102, Feb. 2020.

[52] K. M. Orzech, M. A. Grandner, B. M. Roane, and M. A. Carskadon, "Digital media use in the 2 h before bedtime is associated with sleep variables in university students," *Computers in Human Behavior*, vol. 55, pp. 43–50, Feb. 2016.

[53] G. H. Caumo, D. Spritzer, A. Carissimi, and A. C. Tonon, "Exposure to electronic devices and sleep quality in adolescents: A matter of type, duration, and timing," *Sleep Health*, vol. 6, no. 2, pp. 172–178, Apr. 2020.

[54] F. Inc. "How do I track my sleep with my Fitbit device?" (No Date), [Online]. Available: `https://help.fitbit.com/articles/en_US/Help_article/1314.htm` (visited on 06/16/2022).

[55] Z. Chen *et al.*, "Unobtrusive Sleep Monitoring using Smartphones," in *Proceedings of the ICTs for improving Patients Rehabilitation Research Techniques*, Venice, Italy: IEEE, 2013.

[56] J. S. Bauer *et al.*, "ShutEye: Encouraging awareness of healthy sleep recommendations with a mobile, peripheral display," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, Austin Texas USA: ACM, May 2012, pp. 1401–1410.

[57] N. Daskalova *et al.*, "SleepCoacher: A Personalized Automated Self-Experimentation System for Sleep Recommendations," in *Proceedings of the 29th Annual Symposium on User Interface Software and Technology*, Tokyo Japan: ACM, Oct. 2016, pp. 347–358.

[58] N. Daskalova *et al.*, "SleepBandits: Guided Flexible Self-Experiments for Sleep," in *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, Honolulu HI USA: ACM, Apr. 2020, pp. 1–13.

[59] C. H. Horsch *et al.*, "Mobile Phone-Delivered Cognitive Behavioral Therapy for Insomnia: A Randomized Waitlist Controlled Trial," *Journal of Medical Internet Research*, vol. 19, no. 4, e70, Apr. 2017.

[60] A. Werner-Seidler, Q. Wong, L. Johnston, B. O'Dea, M. Torok, and H. Christensen, "Pilot evaluation of the Sleep Ninja: A smartphone application for adolescent insomnia symptoms," *BMJ Open*, vol. 9, no. 5, e026502, May 2019.

[61] Sleep Foundation. "How to Sleep Better." (Apr. 2009), [Online]. Available: `https://www.sleepfoundation.org/sleep-hygiene/healthy-sleep-tips` (visited on 05/31/2022).

[62] A.D.A.M., Inc. "Changing your sleep habits." (2022), [Online]. Available: `https://www.medlineplus.gov/ency/patientinstructions/000757.htm` (visited on 05/31/2022).

[63] Sleep Foundation. "The Best Ways to Relieve Stress So You Can Sleep Soundly." (Apr. 2022), [Online]. Available: `https://www.sleepfoundation.org/sleep-hygiene/how-to-relieve-stress-for-bedtime` (visited on 06/17/2022).

[64] A. I. Luik, S. D. Kyle, and C. A. Espie, "Digital Cognitive Behavioral Therapy (dCBT) for Insomnia: A State-of-the-Science Review," *Current Sleep Medicine Reports*, vol. 3, no. 2, pp. 48–56, Jun. 2017.

[65] F. C. Brown, W. C. Buboltz, and B. Soper, "Relationship of Sleep Hygiene Awareness, Sleep Hygiene Practices, and Sleep Quality in University Students," *Behavioral Medicine*, vol. 28, no. 1, pp. 33–38, Jan. 2002.

[66] K. Stawarz, A. L. Cox, and A. Blandford, "Beyond Self-Tracking and Reminders: Designing Smartphone Apps That Support Habit Formation," in *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, Seoul Republic of Korea: ACM, Apr. 2015, pp. 2653–2662.

[67] K. Stawarz, B. Gardner, A. Cox, and A. Blandford, "What influences the selection of contextual cues when starting a new routine behaviour? An exploratory study," *BMC Psychology*, vol. 8, no. 1, p. 29, Dec. 2020.

[68] K. Stawarz, M. D. Rodríguez, A. L. Cox, and A. Blandford, "Understanding the use of contextual cues: Design implications for medication adherence technologies that support remembering," *DIGITAL HEALTH*, vol. 2, p. 205 520 761 667 870, Jan. 2016.

[69] C. Pinder, J. Vermeulen, A. Wicaksono, R. Beale, and R. J. Hendley, "If this, then habit: Exploring context-aware implementation intentions on smartphones," in *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services Adjunct*, Florence Italy: ACM, Sep. 2016, pp. 690–697.

[70] A. Wicaksono, R. J. Hendley, and R. Beale, "Using Reinforced Implementation Intentions to Support Habit Formation," in *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems*, Glasgow Scotland Uk: ACM, May 2019, pp. 1–6.

[71] C. Stecher, M. Sullivan, and J. Huberty, "Using Personalized Anchors to Establish Routine Meditation Practice With a Mobile App: Randomized Controlled Trial," *JMIR mHealth and uHealth*, vol. 9, no. 12, e32794, Dec. 2021.

[72] I. Renfree, D. Harrison, P. Marshall, K. Stawarz, and A. Cox, "Don't Kick the Habit: The Role of Dependency in Habit Formation Apps," in *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, San Jose California USA: ACM, May 2016, pp. 2932–2939.

[73] C. Blume, C. Garbazza, and M. Spitschan, "Effects of light on human circadian rhythms, sleep and mood," *Somnologie*, vol. 23, no. 3, pp. 147–156, Sep. 2019.

[74] F. Wang *et al.*, "The effect of meditative movement on sleep quality: A systematic review," *Sleep Medicine Reviews*, vol. 30, pp. 43–52, Dec. 2016.

[75] A. Gotter. "4-7-8 Breathing: How It Works, How to Do It, and More." (Apr. 2018), [Online]. Available: `https://www.healthline.com/health/4-7-8-breathing` (visited on 01/28/2023).

[76] M. K. Scullin, M. L. Krueger, H. K. Ballard, N. Pruett, and D. L. Bliwise, "The effects of bedtime writing on difficulty falling asleep: A polysomnographic study comparing to-do lists and completed activity lists." *Journal of Experimental Psychology: General*, vol. 147, no. 1, pp. 139–146, Jan. 2018.

[77] S. M. Toepfer, K. Cichy, and P. Peters, "Letters of Gratitude: Further Evidence for Author Benefits," *Journal of Happiness Studies*, vol. 13, no. 1, pp. 187–201, Mar. 2012.

[78] M. E. Ellithorpe, E. Ulusoy, A. Eden, L. Hahn, C.-L. Yang, and R. M. Tucker, "The complicated impact of media use before bed on sleep: Results from a combination of objective EEG sleep measurement and media diaries," *Journal of Sleep Research*, vol. 31, no. 5, Oct. 2022.

[79] J. L. Derrick, S. Gabriel, and K. Hugenberg, "Social surrogacy: How favored television programs provide the experience of belonging," *Journal of Experimental Social Psychology*, vol. 45, no. 2, pp. 352–362, Feb. 2009.

[80] U.S. Departement of Veterans Affairs. "Insomnia Coach." (No Date), [Online]. Available: https://mobile.va.gov/app/insomnia-coach (visited on 01/27/2023).

[81] A. L. Boggiss, N. S. Consedine, J. M. Brenton-Peters, P. L. Hofman, and A. S. Serlachius, "A systematic review of gratitude interventions: Effects on physical health and health behaviors," *Journal of Psychosomatic Research*, vol. 135, p. 110 165, Aug. 2020.

[82] M. Jackowska, J. Brown, A. Ronaldson, and A. Steptoe, "The impact of a brief gratitude intervention on subjective well-being, biology and sleep," *Journal of Health Psychology*, vol. 21, no. 10, pp. 2207–2217, Oct. 2016.

[83] Sleep Foundation. "How Drinking Water Before Bed Impacts Sleep." (Aug. 2021), [Online]. Available: https://www.sleepfoundation.org/nutrition/drinking-water-before-bed (visited on 01/28/2023).

[84] E. Finucane *et al.*, "Does reading a book in bed make a difference to sleep in comparison to not reading a book in bed? The People's Trial—an online, pragmatic, randomised trial," *Trials*, vol. 22, no. 1, p. 873, Dec. 2021.

[85] L. Harmat, J. Takács, and R. Bódizs, "Music improves sleep quality in students," *Journal of Advanced Nursing*, vol. 62, no. 3, pp. 327–335, May 2008.

[86] P. M. Zoccola, S. S. Dickerson, and S. Lam, "Rumination Predicts Longer Sleep Onset Latency After an Acute Psychosocial Stressor," *Psychosomatic Medicine*, vol. 71, no. 7, pp. 771–775, Sep. 2009.

[87] CPAP. "Keeping it Clean: How a Clean House Impacts Our Sleep." (Jan. 2020), [Online]. Available: https://www.cpap.com/blog/keeping-clean-clean-house-impacts-sleep/ (visited on 01/28/2023).

[88] E. C. Harding, N. P. Franks, and W. Wisden, "The Temperature Dependence of Sleep," *Frontiers in Neuroscience*, vol. 13, p. 336, Apr. 2019.

[89] P. Strøm-Tejsen, D. Zukowska, P. Wargocki, and D. P. Wyon, "The effects of bedroom air quality on sleep and next-day performance," *Indoor Air*, vol. 26, no. 5, pp. 679–686, Oct. 2016.

[90] K. L. Fismer and K. Pilkington, "Lavender and sleep: A systematic review of the evidence," *European Journal of Integrative Medicine*, vol. 4, no. 4, pp. 436–447, Dec. 2012.

[91] S. Haghayegh, S. Khoshnevis, M. H. Smolensky, K. R. Diller, and R. J. Castriotta, "Before-bedtime passive body heating by warm shower or bath to improve sleep: A systematic review and meta-analysis," *Sleep Medicine Reviews*, vol. 46, pp. 124–135, Aug. 2019.

[92] G. S. Passos, D. Poyares, M. G. Santana, S. A. Garbuio, S. Tufik, and M. T. Mello, "Effect of Acute Physical Exercise on Patients with Chronic Primary Insomnia," *Journal of Clinical Sleep Medicine*, vol. 06, no. 03, pp. 270–275, Jun. 2010.

[93] B. Gardner, C. Abraham, P. Lally, and G.-J. de Bruijn, "Towards parsimony in habit measurement: Testing the convergent and predictive validity of an automaticity subscale of the Self-Report Habit Index," *International Journal of Behavioral Nutrition and Physical Activity*, vol. 9, no. 1, p. 102, 2012.

[94] C. A. Roberto and I. Kawachi, Eds., *Behavioral economics and public health*. Oxford ; New York: Oxford University Press, 2016.

[95] C. E. Carney *et al.*, "The Consensus Sleep Diary: Standardizing Prospective Sleep Self-Monitoring," *Sleep*, vol. 35, no. 2, pp. 287–302, Feb. 2012.

[96] L. Tonetti, R. Mingozzi, and V. Natale, "Comparison between paper and electronic sleep diary," *Biological Rhythm Research*, vol. 47, no. 5, pp. 743–753, 2016.

[97] T. Kawada, "Agreement rates for sleep/wake judgments obtained via accelerometer and sleep diary: A comparison," *Behavior Research Methods*, vol. 40, no. 4, pp. 1026–1029, Nov. 2008.

[98] K. Kim, A. Erickson, A. Lambert, G. Bruder, and G. Welch, "Effects of Dark Mode on Visual Fatigue and Acuity in Optical See-Through Head-Mounted Displays," in *Symposium on Spatial User Interaction*, New Orleans LA USA: ACM, Oct. 2019, pp. 1–9.

[99] V. Braun and V. Clarke, "Using thematic analysis in psychology," *Qualitative Research in Psychology*, vol. 3, no. 2, pp. 77–101, Jan. 2006.

[100] B. Knäuper, M. Roseman, P. J. Johnson, and L. H. Krantz, "Using Mental Imagery to Enhance the Effectiveness of Implementation Intentions," *Current Psychology*, vol. 28, no. 3, pp. 181–186, Sep. 2009.

[101] B. Gardner, P. Lally, and J. Wardle, "Making health habitual: The psychology of 'habit-formation' and general practice," *British Journal of General Practice*, vol. 62, no. 605, pp. 664–666, Dec. 2012.

[102] C. Horsch *et al.*, "Reminders make people adhere better to a self-help sleep intervention," *Health and Technology*, vol. 7, no. 2, pp. 173–188, Nov. 2017.