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DESIGN AND EVALUATION OF THE SOUNDASLEEP APP: THE IMPACT OF EMOTIONAL STATES ON SOUND PREFERENCES FOR SLEEP

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ABSTRACT

Sleep is essential in our lives. Unfortunately, many individuals suffer from a lack of sleep and sleep disorders, which negatively impact their daily lives and cause many problems. Feeling negative emotions during the day can be a reason for sleep deprivation. On the basis of a study which explored how emotional states influence sound preferences for sleep, we have developed the SoundAsleep app. After the user answers questions about their emotional state, the app suggests three sounds that can help them fall asleep. We evaluated the app - its impact on sleep quality and more generally how people experienced using it - with twenty participants who used it every day for at least one week. Results from this evaluation further support that a relationship between emotional states and sound preferences for sleep exists. Finally, we suggest new directions for research and development of effective sound-based sleep aids.

Keywords: *sleep, sound, emotions, app development, evaluation*

1. INTRODUCTION

Many people struggle with sleep due to many factors, including their emotional state before bed [1]. While research has shown that sound influences emotions and sleep quality [2, 3], there is limited knowledge on how sound can affect the regulation of emotions before going to bed and promote sleep.

This study evaluates a sleep aid application designed to suggest sounds based on users' emotional states to facilitate relaxation and sleep. The SoundAsleep app was developed based on insights from research investigating this relationship [4]. A 13-day experiment, which included participants using the app for one week, was conducted to assess the app's effectiveness in real-world conditions. We gathered and analysed data on participants' experiences and sleep quality. The experiment was carried out in two distinct rounds (with 11 and 9 participants respectively) to compare the results and assess the stability of the app's effectiveness.

2. BACKGROUND

Good sleep enhances cognitive function and physical well-being throughout the day, as well as helps regulate human emotions [5]. People with sleeping disorders, such as insomnia, suffer from daytime fatigue, difficulty concentrating, mood disturbances like irritability or anxiety, and short-term memory impairment [6]. Good sleep quality is characterized by shorter sleep latency, fewer awakenings, and reduced wake time after sleep onset [7]. Research has shown that achieving good sleep quality promotes fewer negative moods throughout the day and reduces daytime sleepiness and fatigue [8].

People experiencing sleep deprivation often seek ways and techniques to improve their sleep at night. These techniques can include pharmacological and non-pharmacological methods [9, 10]. Auditory stimuli have become a popular non-pharmacological approach for enhancing sleep and improving sleep quality. Sounds such as white and pink noise, music, binaural beats, and natural sounds have proven to be effective tools for better

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sleep quality [3, 11]. Lullabies are a natural practice used to help children fall asleep, and music can serve a similar purpose. Research has found that music characterized by a lower tempo, lower loudness, and lower energy is more likely to facilitate sleep [12].

Technology has played an essential role in providing an easy way for the user to integrate sleep enhancement methods in their everyday life. A study done on the meditation app *Calm* [1] , a relaxation app that includes breath techniques, sounds, music and stories, reported that participants have felt improvement in their sleep, with the majority stating that the app facilitated falling asleep, less awakening and getting restful sleep [13]. Another recent study about *Moshi*, an audio-based sleep aid made to improve sleep for children and parents with help of story telling and sounds, reported improvement in sleep health for all children and increased sleepiness for parents [14]. Several commercial mobile apps use auditory stimuli aiming to reduce sleep latency using nature sounds and instrumental music [15]. Two examples are: *Endel* [2] and *Sleep Cycle* [3] , which use sounds for focus and relaxation to enhance sleep. Finally, recent design research is exploring a variety of interfaces to embed sonic interventions in the bedroom. Yūgen Cloudstone Echo, for example, is a design for a speaker (the Stone) and charging base (the Cloud) inpired by the Zen concept of Yūgen. The design uses different colored noise and ASMR together with light to create a claming sleeping environment [16]. A smart pillow described in [17] uses a high-fidelity mobile application to control sound, temperature, and to record sleep data.

One of the causes of sleep deprivation is negative emotions, such as stress and worry [18]. Sounds have been proven to effectively modulate emotions and, therefore, potentially help people sleep [2, 19]. Research has also shown that sounds can lower cortisol levels during active auditory stimulation at night [20].

Our recent study [4], found that people's preferences for sounds to facilitate sleep change depending on their emotional state before going to bed. Seventy-eight participants ranked six sounds (Rain, Underwater, Singing Bowls, Birds, Crickets, Chimes) when imagining experiencing four emotions (Happy, Sad, Calm, Stressed) before going to bed. The results indicated that Rain was the preferred sound across all emotions, while Chimes was the least preferred sound. Furthermore, results showed that sounds such as Rain, Underwater, and Singing Bowl are preferred for negative emotional states, while the sounds of Birds, Crickets, and Rain are selected more often for positive emotional states. Finally, results varied depending on gender and whether participants regularly used audio for sleep.

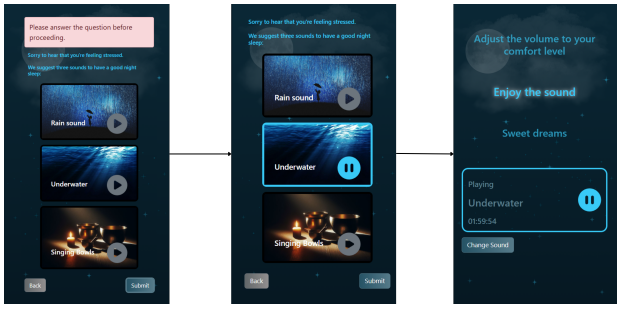

Figure 1. Three screenshots from the application. The first shows the error handling. The second shows the sound card selection and play/pause options. The last shows the messages after sound selection.

3. METHOD

SoundAsleep was developed based on the findings and the initial app design described in [4]. It is designed to suggest sounds for sleep based on the user's emotional state. The app was evaluated and tested in a 13-day-long experiment, which involved using the app before sleep for a minimum of one-week.

3.1 SoundAsleep app

The app was developed as a web application using *React JS* [4] instead of a native application for mobile phones. This decision aimed to create a simple and easy-to-use app that runs across different operating systems and devices. It uses *MongoDB* [5] to store user data. Each user has a unique ID that is saved in the database. The collected data is later analyzed to gain insights into user interactions and preferences.

To achieve the goal of facilitating sleep, the app was designed to promote calmness, and not cause stress. The

[1] https://www.calm.com
[2] https://endel.io/
[3] https://sleepcycle.com/
[4] https://react.dev/
[5] https://www.mongodb.com/

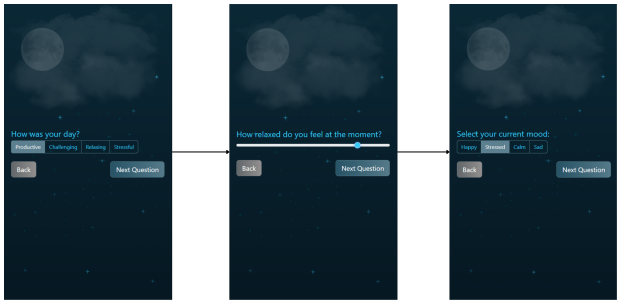

Figure 2. Initial 3 questions about mood.

design was influenced by Moraveji and Soesanto's design principles [21] which aim to minimize the number of stressors in an interface. For example, the app presents as little data as possible on the display, it uses apologetic and polite tones such as *"Sorry to hear that you are feeling sad"*, and has minimal content to reduce time spent on the task and create a more efficient and calming user experience. The app also includes error handling. For example, if a user misses selecting an option, it displays a prompt saying, *"Please answer the question before proceeding"* (see Fig.1).

In the app, the user is asked to answer a couple of questions about their day and their emotions (see Fig.2). Based on the user's responses, the application suggests three sounds that could facilitate sleep based on the emotional state selected by the user. The suggestions are based on the findings in [4]. The sounds are displayed on large "cards" to simplify user interaction and focus attention. Users can preview the sounds before making their final choice. The app provides visual cues as feedback. For instance, when the user clicks on a sound card to listen to the sound, the border color of the card changes, and the *play* icon changes to a *pause* icon, indicating that the sound is playing (see fig.1). The font type and size have been selected to minimize eye strain when reading in dark environments. A background with darker colors is designed to make more comfortable to use the app under low-light conditions. The color blue is chosen because of its association with calmness [22]. After sound selection, the page displays some simple messages to users such as *"Adjust the volume to a comfortable level"*, *"Enjoy the sound"*, and *"Sweet dreams"*. These messages are accompanied by a glowing animation that transitions smoothly from one statement to another (Fig.1). The animation enhances readability and adds a visual element to the experience.

Finally, to avoid playing the sound all night, a timer was set so that a selected sound will automatically stop after 2 hours. During playback, the user can pause and play at any time, and the visible timer stops along with the sound. Additionally, the user has the flexibility to change the sound if desired.

3.2 Sound Stimuli

The first round of the experiment (R1) uses sounds from our previous study [4]. The second round (R2), uses the same sounds with slight improvements on the basis of feedback gathered during R1. The sound that was most improved between R1 and R2 is the Birds sound. In R1 this was considered too repetitive. In R2 the variability was increased and the signal to background noise ratio slightly reduced so the birds sounds would not be too prominent. Improvements for other sounds simply meant to increase their inherent variability to avoid any sense of repetition.

The possible sounds for each emotion is detailed in Table 1. For this study, the sounds were edited using Audacity. The final audio clips used in the app were approximately 30 minutes in length to minimize any noticeable transitions. These 30 minutes audio clips were then looped in the app to last for a maximum of 2 hours. All audio clips were edited and normalized to -30 LUFS. Users could adjust the volume as needed.

Table 1. Top sound preferences for each emotion.

Emotion	Top Three Sound Choices
Happy	Rain, Birds, Crickets
Sad	Rain, Underwater, Singing Bowls
Calm	Rain, Singing Bowls, Crickets
Stressed	Rain, Underwater, Singing Bowls

3.3 Participants

In R1, 11 participants were recruited. The participants included 6 males and 5 females, with an average age of 30 (SD = 8.9). Almost half (7 out of 11) of the participants stated that they have regular sleeping hours, averaging 7.2 hours of sleep each night. Most participants stated that they sleep alone, except for two who occasionally share a bed with a partner. Five out of 11 participants stated that they occasionally use sounds to aid sleep: 4 listen to podcasts and audiobooks, and 1 listens to music. In R2,

9 participants were recruited (3M, 6F; mean=27,SD=8.1). Six participants indicated that they have regular sleeping hours. The average sleep duration was 7.1 hours. Four participants stated that they normally sleep with a partner, and 1 with a pet. Two stated to listen to podcasts before sleeping, 2 listen to music, and 1 listens to natural sounds.

3.4 Experiment

In both rounds, participants were asked to use the app before bed every night for seven nights. During the 3 days prior to starting using the app, they were asked to submit a sleep diary every morning, answering questions about their experience the night before. The form included questions from *The Consensus Sleep Diary* [23]. The sleep diary also collected self-reported data on participants' sleep onset latency and sleep quality. After the seven nights using the app, participants were asked to complete the sleep diary for three more days making the overall experiment 13 days long. This approach aimed to gather information about the participants' normal sleep patterns and allows for comparison with experiences of sleep while using the app.

Participants were also asked to complete a short survey before the start of the experiment to collect data about their sleep habits. They were provided with instructions on how to use the app and informed that they could withdraw from the experiment at any time. They were told that they could stop the sound from playing at any time. At the end of the experiment, participants were asked to complete a final survey. This helped us gathering feedback on their experience of using sound for sleep and, using questions from the*User Experience Questionnaire* [24], on the app.

4. RESULTS

The results will be presented as a comparison between the two experiment rounds. The few instances in which a few participants missed using the app, were excluded from analysis.

4.1 Sleep Quality Index

Participants rated their *Sleep Quality Index* (SQI) in the sleep diary every morning throughout the experiment on a scale from 1 to 5, where 5 indicates good sleep and 1 indicates poor sleep. The average index for participants during the experiment was 4 out of 5 in both R1 and R2. To illustrate the variability of this index, the most as well as the least variable patterns from R1 and R2 are shown in Fig.3. We can see that sleep quality can vary a lot with some participants having a stable sleep quality index throughout the experiment, while others experience significant fluctuations from day to day.

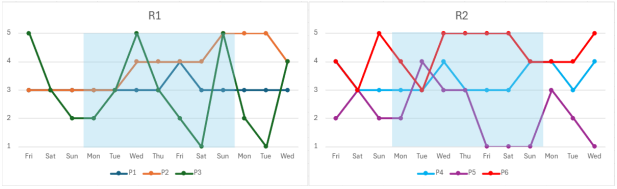

Figure 3. Examples of Sleep Quality Index variability among participants from R1 and R2. The blue highlighted area represents the week where participants used the SoundAsleep app.

4.2 Sounds selections

Participants reported experiencing different moods while using the app. In R1, the mood "Calm" was reported 41 times, "Stressed" 19 times, "Happy" 11 times, and "Sad" twice. Each participant reported at least one mood during the week. In R2, "Calm" was reported 28 times, "Stressed" 9 times, "Happy" 8 times, and "Sad" 5 times. Notably, one participant selected the mood "Calm" every day during the experiment.

When comparing the choice of sounds for each mood in both rounds, the Rain sound was the most frequently selected 45 times in R1 and 23 in R2. A key difference is that Rain was predominantly chosen for the mood "Stressed" in R1, whereas in R2, the Underwater sound was selected more often for "Stressed". The Cricket sound was selected similarly across R1 and R2. This was the second most selected sound for "Calm". Singing Bowls was also selected similarly in R1 and R2, with 7 participants selecting it for "Calm" in R1 and 5 in R2. The Birds sound was the least preferred sound in both R1 and R2 despite slight improvements in the sound between the two rounds. Fig.4 shows a comparison between R1 and R2 in terms of how often each sound was selected based on mood.

4.3 Sound relaxation

Participants self-evaluated whether the sound was effective in helping them relax before sleeping. They selected one of the following options: "Yes, it helped me relax", "Somewhat, but it wasn't completely effective",

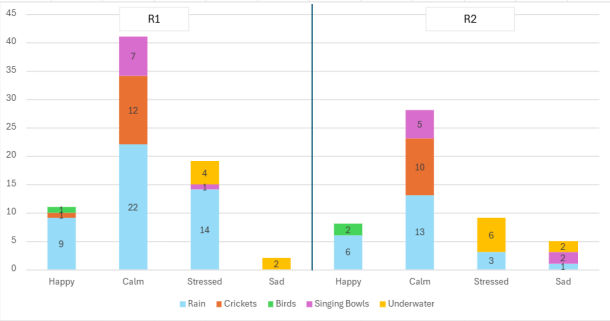

Figure 4. These images shows the distribution of Sound Choices by Emotional State.

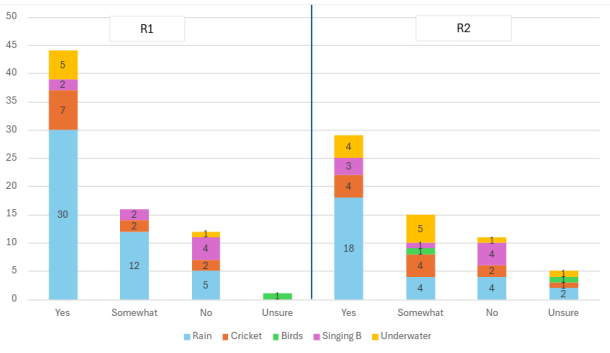

Figure 5. This plot compares the results of the first and second experiment rounds, showing participant responses regarding the efficacy of sounds for relaxation, correlated with the specific sound selections made.

"No, it did not improve my relaxation", and "Unsure/I don't remember". Fig.5 illustrates the relation between sound types and their perceived effect on relaxation in both rounds. The Rain sound was perceived to be the most effective in promoting relaxation compared to other sounds. The 'Birds" sound received unclear relaxation ratings, with one participant in each round selecting "Unsure" when evaluating its effect. The Underwater sound appeared to be slightly more effective in R2 than R1, while the Singing Bowls sound seems to be considered the least relaxing in both R1 and R2.

4.4 Summary of comments

In this section we report the results of the final survey in which questions such as: *"Describe your rating of the overall experience of falling asleep with sound in the past week."* and *"Describe whether the sounds affected your emotional state."* were included.

Nine participants from R1 reported a calming and relaxing effect when listening to the sounds, particularly when they were stressed. One participant noted that the sounds helped them relieve stress, but questioned their usefulness when they already felt calm. In contrast, 2 participants from R2 stated that the sounds were relaxing only when they were not feeling stressed. Some sounds, however, were described as annoying or frustrating: *"On stressed nights where my mind thought to much, the sounds were to loud, almost annoying as I channeled my frustration on the sound. Those nights I had to only hear my own thoughts and nothing else that would disturb me."* Some participants reported that the sounds helped them focus their minds and reduce overthinking: *"It kept myself from overthinking too much during the night"* and *"I remember one night vividly where the sound of rain smattering really made me 'sink' into the pillow. I remember thinking how the sounds 'replaced' a part of my usual thoughts, which would have been buzzing in different directions."*

Three participants from R1 and two from R2 mentioned that, initially, listening to the sounds was annoying, but after a few nights, they adapted, and it became relaxing. One participant stated that they missed using the sounds after the experiment: *"At the beginning it felt annoying, but from the third day onwards I was looking forward to listening to the sound to help me relax. During the three days after using the app, I missed the sounds."*

There were mixed responses regarding which sound had the most relaxing effect. The majority identified Rain as the most positively received due to its familiarity and calming nature: *"I would say especially the rain sounds, which made me imagine summer days and miss them. It felt like I was sleeping with the window open, listening to the rain outside"*. Underwater and Crickets were also considered positively. However, Birds and Singing Bowls were the most frequently negatively perceived, as they were perceived as too high-pitched or associated with waking up and stress.

Of the 20 participants surveyed, 14 indicated that they would occasionally use the app in the future, 4 were certain they would use it regularly, while 2 stated they would not use it at all.

4.5 App User Experience Evaluation

The app user experience was evaluated by rating the attributes of the User Experience Questionnaire [24] on a scale from 1 to 7, where 1 represents a negative perception and 7 represents a positive perception. Fig.6 shows the results of the evaluation and a comparison between the first and second round.

In general, the average ratings were very similar across both rounds, except for *Efficiency* and *Simplicity*, which were rated higher by participants in R1. Additionally, *Understandability* received relatively high ratings in both trials, indicating that the app was easy to understand. However, participants in R2, on average, rated *Learnability* lower than those in R1. This was mainly due to one participant who did not initially realize that they needed to click the submit button in order to proceed to the player page.

Participants from both rounds suggested several improvements. They expressed a desire for a greater variety of sounds, for example stating that they wished for *" higher quality sounds, more variance, layers, possibility to combine into a personalised soundscape"*. One participant from R2 mentioned the possibility to adjust the duration of sound playback rather than being limited to a fixed period (2 hours). Others suggested including more emotions to choose from, or allowing users to select multiple emotions simultaneously. Finally, participants provided feedback on usability improvements. For example, they noted that the slider used to indicate relaxation levels was missing numerical markers, which they would have found useful.

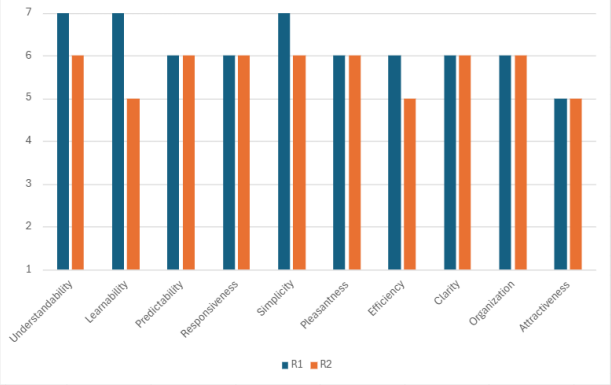

Figure 6. This plot compares the results from R1 and R2, showing the average user ratings for app features for each feature.

5. DISCUSSION

5.1 Sound selections

Rain was the most chosen sound in both rounds, confirming the outcome of [4], which concludes that rain is appealing to us independently of our mood. The second most popular sound was Crickets, which was mostly associated with calmness. When feeling stressed, participants preferred Underwater Sounds, especially in R2. These results are in line with findings in [4].

Four participants from both R1 and R2 consistently chose the Rain sound, whereas 1 participant from R2 always chose the Crickets sound. Other participants selected different sounds depending on their emotions.

Participants' preferences for sounds often seemed to be influenced by contextual factors and personal experiences. For example, Rain was considered a familiar sound for many as it is common in Sweden, and many participants are accustomed to sleeping to the sound of rain. Additionally one participant from R2 mentioned that they did not like the particular rain sound used in the app because it was unfamiliar to them: *"I felt that the rain sound didn't sound like real rain. I come from a tropical country where it rains a lot, and I find very relaxing to sleep to the sound of rain, but the sound in the app was more like continuous, nonstop rain, which doesn't feel very natural to me."*

Personal memories also played a role in sound selections. One participant from R1 consistently chose to listen to Crickets and mentioned that the sound evoked memories of summer vacations.

5.2 Effectiveness in aiding sleep

Adaptation seems to play a role in sound effectiveness to aid sleep. Some participants mentioned that they initially felt annoyed when listening to these sounds or specific sounds, but after a few nights, they adapted to them, and the sounds gradually helped them relax. We suggest that a longer study could investigate this aspect as in depth knowledge on how this adaptation occurs could lead to the development of more effective sleep aids.

Most participants indicated that Rain was the most effective sound for aiding relaxation. This might be because this sound is quite similar to noise which has been shwon to help sleep. Several participants mentioned that the rain sounds helped them reduce overthinking and focus their minds. Birds sounds were not preferred among partic-

ipants even after improving the sound between R1 and R2. Several participants mentioned that they associated the sound of birds with waking up in the morning, making it difficult to fall asleep to them. Participants from R2 also mentioned that Singing Bowls were associated with yoga but, due to the high pitch of the sound in the app, they did not find it very relaxing.

The sounds were generally found to be helpful in reducing stress, as most participants who selected stress as their emotion stated that the sounds helped or somewhat helped them relax. However, one participant from R2 clearly expressed that when feeling stressed, they found any of the sounds irritating and preferred a quiet room.

5.3 App Usability

Choosing to develop a web app instead of a mobile app proved to be successful as all users were able to access the website regardless of their operating system. Overall, feedback on the app was positive, with participants rating it highly for simplicity and ease of understanding. Users also appreciated the clean and minimalistic design, noting that it was easy to navigate without unnecessary distractions. Participants from R2 were more critical of the app. This might be because most of them were students of interaction design, whereas participants from R1 represented a more general audience without particular expertise in technology. The app received some low scores for "Responsiveness", which might be due to slow internet connections and the size of the audio files used. Additionally, the app received slightly lower scores for "Learnability", particularly in R2. For future improvements, clearer labels and instructions could be added to prevent this. Enhancing the app's responsiveness should also be prioritized. Regarding the sounds, results indicate that a greater variety of options would benefit users. Additionally, allowing users to choose between multiple versions of the same sound could be valuable, as individual experiences of a certain sound vary significantly.

5.4 Limitations

The experiment did not account for variations in sleep environments. Factors include room temperature, ambient noise, lighting, sleeping alone or with someone, and the presence of pets. As these parameters were not controlled, it is likely that they affected the results. On the other hand, the fact that this study confirms some of the results of our previous study on sound preferences for sleep seems to indicate that the main findings are quite independent of sleep environment conditions.

Another limitation is the lack of objective measurement tools, such as EEG, polysomnography, or wearable sleep trackers. These tools could provide a more accurate assessment of participants' sleep quality, sleep duration, and sleep onset latency.

6. CONCLUSION

The study evaluated the SoundAsleep app which provides sounds to help sleep based on the user's emotional state. Results were encouraging and participants found that they could adapt to the sounds quickly. The app received positive feedback, but improvements in clarity and responsiveness are needed.

7. ACKNOWLEDGMENTS

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