Towards Understanding the Design of Positive Pre-sleep Through a Neurofeedback Artistic Experience

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ABSTRACT

Poor sleep has been acknowledged as an increasingly prevalent global health concern, however, how to design for promoting sleep is relatively underexplored. We propose neurofeedback technology may potentially facilitate restfulness and sleep onset, and we explore this through the creation and study of "Inter-Dream", a novel multisensory interactive artistic experience driven by neurofeedback. Twelve participants individually rested, augmented by Inter-Dream. Results demonstrated: statistically significant decreases in pre-sleep cognitive arousal (p = .01), negative emotion (p = .008), and negative affect (p = .004). EEG readings were also indicative of restorative restfulness and cognitive stillness, while interview responses described experiences of mindfulness and playful self-exploration. Taken together, our work highlights neurofeedback as a potential pathway for future research in the promotion of sleep, while also suggesting strategies for designing towards this within the context of pre-sleep.

CCS CONCEPTS

• Human-centered computing → Ubiquitous and mobile computing design and evaluation methods • Human-centered computing → Interaction design

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KEYWORDS

Interactive Art; Brain-Computer Interface; Multisensory Experience; Neurofeedback; Pre-Sleep

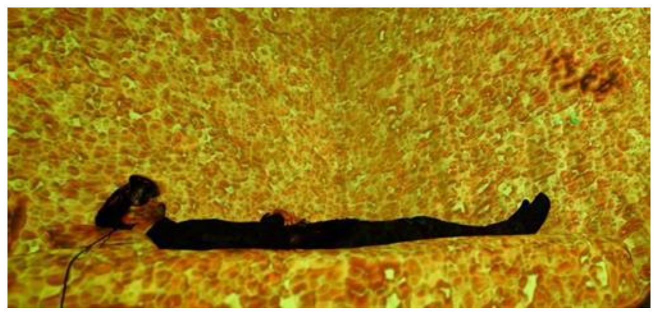

Figure 1: The Inter-Dream system. Participants manipulate graphical imagery through EEG, which projected around the room and in VR while resting in an interactive bed.

1 INTRODUCTION

Sleep and technology are usually two disparate concepts notoriously conceived as being grossly incompatible. The problem of inefficient or insufficient sleep has been acknowledged as an increasingly prevalent global health concern [13, 4, 8], complicit in a myriad of physiological and psychological disorders. As such, a notable effort has been made in identifying factors contributing to this trend.

In this paper, we explore the possibility of challenging this relationship, designing toward a technological promotion of sleep as opposed to the disruption of sleep, in a non-clinical context through "Inter-Dream". Inter-Dream is a multisensory artistic experience that dynamically reacts to user's electrophysiology through neurofeedback (figure 2). Through a user study, the potential for such a system to induce psychophysiological pre-sleep states necessary for sleep onset in a non-clinical population was assessed through psychometric and electrophysiological measures. Furthermore, through the discussion of insights gained from qualitative interviews, we provide strategies toward the design of systems that facilitate the user's ability to dualistically explore, monitor and influence their psychophysiological processes, while also affording the presentation of these processes as creative expression, or art.

Figure 2: The EEG headset (left) and the active Inter-Dream system (right).

Our results contribute a starting point for sleep researchers, which highlight the potential application of similar neurofeedback systems promoting sleep health through technological induction of positive pre-sleep states.

Additionally, the system's mechanisms provide participants an affordance of self-exploration and creative expression in the pre-sleep domain. We offer this system as a case study in designing for the facilitation of creative expression and playful exploration to promote positive pre-sleep.

2 HCI AND SLEEP TECHNOLOGY

In designing toward the promotion of sleep, it is first necessary to consider factors detrimental to its onset.

2.1 Sleep Disruption

It has been demonstrated that technology, namely the usage of electronic media is consistently related to the disruption of sleep onset and duration [7, 2]. Specifically, the stimulus of bright, high-energy, blue-wave LED light emitted by screens, paired with psychological arousal intrinsic in active technology (such as social media), interfere with the body's natural circadian rhythms. These mechanisms in turn delay the homeostatic production of melatonin and other physiological processes necessary to the onset of sleep [29, 19].

Yet this negative interaction does not occur in isolation. Rather, it builds upon societal stressors, recognized as significant contributors toward declining quality of sleep [30]. For example, work related stressors such as interpersonal conflict, workload, and perceived ambiguity have been demonstrated to be closely related to a decrease in sleep quality [14]. Furthermore, this relationship has shown to be mediated by preservative cognitions (i.e. rumination), suggesting the cognitive representation of stress related content before sleep is a notable component in this interaction [3].

Similar mediational properties are also shared with sleep, societal stressors, and mood, specifically with negative affectivity as the mediator. In detail, in a study of 467 participants, Fortunato and Harsh [14] examined the influence of affectivity and work-related stressors on a multi-dimensional measure of sleep. Findings demonstrated poorer sleep quality in those with high negative affectivity, partially supporting the notion that negative affectivity operates to amplify the individual's perceptions of negative environmental events, thereby exacerbating already existent stressors.

2.2 Predictors of Good Sleep

Good sleep is acknowledged to be preceded by a characteristic set of specific cognitive and mood states, as well as physiological changes. The cognitive focus of good sleepers has been noted to be a relaxed and restful voluntary phenomenon, in contrast to bad sleepers, who report a cognitive focus on unpleasant and intrusive worries and stressors because of involuntary mental rehearsal of the past day's events [19]. Similarly, good sleepers are more likely to report positive mood before sleep than poor sleepers or insomniacs, who more often present anxious or depressed moods [1]. Lastly, a healthy transition from wakefulness to sleep is characterized by a somatically noticeable change in physiological processes driven by an increased engagement of the parasympathetic nervous system [6].

When described from an electrophysiological perspective, these healthy transitions into sleep are represented by distinctive EEG activity. When assessing sleep onset through measures of absolute power spectral density, good sleepers reportedly demonstrate higher power levels in the delta spectrum relative to other spectrums, than those experiencing poor sleep [25]. Additionally, healthy sleep onset is further marked by a notable drop in power levels of the alpha frequency spectrum during the later stages of sleep onset.

Taken together, existent literature suggests the factors explanatory of sleep disruption can be operationalized as a set of pre-sleep (occurring prior to sleep onset) physiological and psychological phenomena. Namely, the experiences of high somatic and cognitive pre-sleep arousal, and high negative mood and affect in the context of pre-sleep, are detrimental to the healthy onset of sleep. Thus, the design of technologies which can assist the facilitation of sleep onset should consider these negative factors.

2.3 Designing for Sleep

2.3.1 Contemporary Sleep-Technology. In its current state, HCI exploration into designing technology for sleep is largely dominated by the notion of sleep tracking. While this approach purports the facilitation of user awareness of their sleeping habits, its purely observational nature neglects to actively address any of the pre-sleep factors earlier identified. Rather, users have reported increased awareness of sleep habits but no subsequent improvements of sleep [23].

In considering the earlier establishment of the detrimental use of technology pre-sleep, the most intuitive solution to this issue would be the discontinuation of electronic media consumption leading up to bedtime, which is the main suggestion given by research examining this trend. However, many reportingly struggle to eliminate pre-sleep media consumption [12]. In response, some technology focused solutions have involved the development of applications which limit the amount of blue-light emitted by backlit LED screens at a specified time. The rationale is that doing so prior to sleep will mitigate the disruptive effect of blue-wavelength light over melatonin production [39, 17].

However as previously established, it is necessary that technological solutions also address the psychological factors of cognitive arousal, emotion, and affect, for a holistic facilitation of healthy pre-sleep to be achieved. While reducing an individual's exposure to blue light is suitable in addressing physiological concerns, this approach in isolation overlooks the equally integral psychological arousal associated with technology.

2.3.2 *Creative Affordance.* In a more distinctly novel approach to integrating technology and sleep, Haar et al., [18] capitalized on the specific pre-sleep state of hypnagogia to augment human creativity through their "Dormio" interface. In their approach, a robotic sleeping companion, "Jibo" was able to accurately detect when its user entered a state of hypnagogia through muscle control detection. On hypnagogic detection, Jibo speaks to the user on the topic of a pre-programmed prompt, facilitating a conversation of the prompt topic unto the users falling into sleep. As a result, users reported micro-dreams about the prompt topic, thereby illustrating the systems propensity to facilitate augmented creativity. While this system facilitates pre-sleep states the findings of this paper are notable in that they introduced the affordance of creativity in a sleep context.

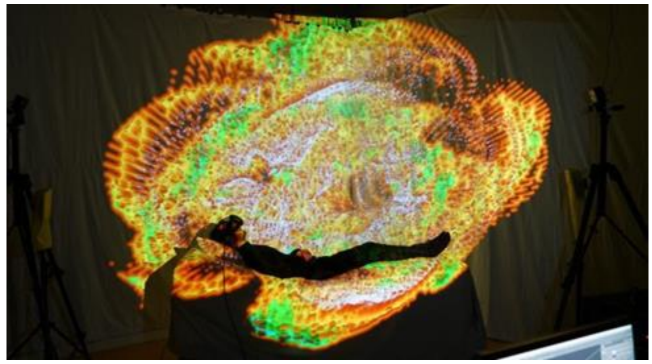

Figure 3: The surrounding pattern is generated by the participant, providing creative affordance.

This is no trivial notion in the context of inducing positive pre-sleep states, as it has been well documented that creative expression is strongly associated with positive effects on emotion and affect [35]. Ultimately, these findings highlight the inclusion of creative affordance as a viable approach to reducing negative emotion and affect, or promoting positive emotion and affect, in the context of pre-sleep (figure 3).

2.3.3 *Multisensory Stimulation.* In a commercial context, another unique approach can be seen in the "Somnox". This system is a pillow-like soft robot intended as a sleeping companion which "breaths" and plays soothing music to facilitate restfulness. Through the evocation of haptic and auditory stimulation, it is proposed that Somnox engages the parasympathetic nervous system through deep conscious breathing, thereby relaxing the individual [36]. While this does not address all factors underlying the facilitation of positive pre-sleep states, it does well to address the somatic expression of pre-sleep arousal through its multisensory stimulation. Additionally, the focus of breathing described here closely relates to mechanisms through which neurofeedback operate, a process strongly tied to both the cognitive and electrophysical self-control.

2.3.4 Neurofeedback. Neurofeedback is a subcategory of biofeedback - the self-monitoring and control of one's own bodily processes normally thought of as involuntary. This is typically implemented through the assistance of bioinformatic and bioimaging technology measuring physiological activity. Neurofeedback is the specific adoption of this biofeedback in the context of observing one's own neural activity, generally achieved via readings of electrical activity emitted through the scalp, read through a non-invasive *electroencephalogram* [45]. The application of this methodology has demonstrated its ability to significantly reduce the problematic symptoms of several psychological and physiological disorders, such as diabetes, anxiety, ADHD, and nocturnal bruxism [41, 24, 9], whilst also reducing stress through facilitating restfulness and relaxation. The profound benefits of this methodology can be seen in its rather recent widespread adoption as a form of, or supplement to psychological and physiological therapy [41].

Its success as a therapeutic tool stems from affording users the ability to observe their own electrophysical activity, representative of their cognitive states. In turn, the ability to observe this phenomenon provokes introspection and mindfulness, drawing the attention of the user toward the active control of their cognitive processes through conscious physiological self-regulation. This is further demonstrated in applications that apply neurofeedback in interactive systems designed for mindfulness. One example of this is "PsychicVR" [1], which pairs BCI with VR to produce an immersive playful experience by allowing users to make changes to a virtual 3D environment when in a focused state of mind, thereby encouraging mindfulness. Similarly, "Inner Garden" [37], an augmented sandbox which uses spatial augmented reality to create a tangible desk top sized living world, draws a user's attention to their emotional state by having these factors influence the sandbox world monitoring EEG and breathing. In turn, this demonstrates the capability of interactive technologies to reflect on emotional or meditative states, promoting cognitive previously established as beneficial to positive pre-sleep.

When considered in the context of sleep, it can be argued that these properties highlight neurofeedback as a promising approach in including both positive somatic and cognitive expression during pre-sleep.

In summary, the consideration of prior research has led to the identification of a set of psychological and physiological pre-sleep factors that would benefit from addressing when designing technology for the induction of sleep. These are pre-sleep arousal (somatic and cognitive), and mood (emotion and affect). Whereas prior works have either directly or inadvertently designed sleep technology to address one of these factors, we have drawn inspiration across previous related works of neurofeedback, creative affordances and multisensory stimulation, to build towards holistically towards all proposed factors of pre-sleep (figure 4).

Figure 4: The Inter-Dream system attempts to build towards a holistic acknowledgement of all proposed factors of pre-sleep.

3 INTER-DREAM

The design of the Inter-Dream system followed the approach of Performance-led research in the wild [4]. In this approach, the design and presentation of an artefact is lead by an artist following artistic processes. In turn, research findings emerge from reflection on the artefact and the participants experience. Considering Inter-Dream specifically, the artefact was originally designed by the artists with the intention of producing an interactive public art instillation which explored the *speculative-future* concept of interpersonally sharing dreams through BCI. Following this, the researchers then sought to explore how this system may alternatively be applied in exploring technological promotion of positive pre-sleep, bringing us to the present study. With this said, we stress that Inter-Dream instillation was not specifically designed with the promotion of healthy sleep in mind. Rather, in considering its componential design, providing multisensory stimulation; and its neurofeedback focus, providing creative affordance and mindful relaxation, it was hypothesized by the researchers that Inter-Dream would help promote positive pre-sleep.

The Inter-Dream installation featured an interactive bed. The angle of the bed's sleeping platform could be adjusted; the position of the sleeper's head and feet could be raised and lowered using a remote control. Additionally, the bed could gently vibrate; this feature was also controlled via a remote control. During each 10-minute session, the participant rested on the bed. One person at a time could engage with our system. After five minutes, the artists would manually adjust the position of the participant's head raising the angle of the top section of the bed. After 7 minutes the artists would raise the lower part of the bed so that the participant's feet were supported in a slightly raised position. Additionally, at the 7-minute point, the artists triggered the bed to vibrate gently. These adjustments were made with the aim of creating optimal comfort for the participant.

During each participant's experience a musical score was played that had been specifically composed by the artists. This musical score was designed to be relaxing with soft elongated tones that may aid the participant in relaxing and being further immersed in a sensory experience.

The two walls at the back of the bed area were projection mapped using a single projector. The projection showed visuals that were animated in response to the participant's brain activity. One person at a time could engage with our system. A "Muse" EEG headset [22] was used to non-invasively monitor the electrical activity of the participants brain, emitted through the scalp. Raw EEG data was wirelessly sent to a mobile device via Bluetooth. From here, real time absolute power values were calculated for Delta(δ) 1-4Hz, Theta(θ) 4-8Hz, Alpha(α) 7.5-13Hz, Beta(β) 13-30Hz, and Gamma(γ) 30-44Hz, frequency bandwidths; while also performing automatic artifact removal [32]. This data was then sent out to our central computer system.

From the central computer, EEG data was interpreted through a custom program in TouchDesigner, a real time graphic generation and projection mapping software. The interpretation of EEG data through TouchDesigner allowed for the real time visualization and artistic abstraction of the participants brain activity as graphical imagery. This imagery was dynamically reactive to the EEG activity of the participant, changing in real time in response to changes in absolute power across each frequency bandwidth communicated from the participants brain. This was achieved by having the RGB color values of the imagery modulated by the absolute power of each frequency bandwidth, with each bandwidth's value being associated with the intensity of a specific color.

Similarly, shape, contrast and amplitude were modulated by the overall intensity of EEG activity given by voltage. Specifically, higher levels of activity resulted in larger and more non-uniformed shape, higher contrast and greater amplitude of the oscillating movement of the imagery. Taken together, this dynamically reactive artistic representation of the participants brain activity forms the neurofeedback component of Inter-Dream. However, it is worth noting that while neurofeedback traditionally provides positive or negative feedback to desired or undesired brain activity, we in contrast implement a more experimental approach that is not precisely a measurement of cognitive states, but rather an artistic representation of EEG activity.

In addition to projection mapping, this imagery was presented specifically to the participant through VR (with the former component being vestigial of the systems origins as a public interactive art installation). The imagery was displayed on both the projection and in VR simultaneously. Both mediums presented the same imagery, however the version presented to the participant in VR was slightly simplified, lacking the "flare effect" which was intermittently present in the projected version (figure 1). This disparity was motivated by a discovery made during the design of the system, in which a feedback loop was often initiated on participants seeing the flare. This was due to the flare being generated from very high overall levels of EEG activity, which was prolonged and further exaggerated by the brain's response to the vibrant visual stimulus, snowballing into a cyclical loop of intense feedback and high levels of neural activity sustaining each other.

Figure 5: This image demonstrates the Inter-Dream system in an idle state. Note the projected graphic is static without EEG input.

4 STUDY

The aim of the present study was to explore the potential for technology to induce psychophysiological pre-sleep states necessary for the onset of sleep through the use of the Inter-Dream system.

4.1 Participants

Twelve participants were recruited for our study, including nine males and three females, with a mean age of 33 (SD = 11.86). The sample was primarily recruited from our university and via word of mouth. All participants were considered of a non-clinical, healthy population. No participants had any prior experience with neurofeedback, and only two had prior experience with virtual reality.

4.2 Procedure

The procedures of the user study were approved by our ethics board (CHEAN, RMIT University). Informed consent was collected from participants before their involvement. Sessions were completed individually, taking a total of 30 – 45 minutes per participant.

4.2.1 Pre-Test. Prior to the use of the Inter-Dream system, an initial baseline measure of participant pre-sleep arousal and emotional states were assessed through the implementation of a battery of self-report psychometric scales. These being the Pre-sleep Arousal Scale (PSAS) and the Positive and Negative Affect Schedule – Extended (PANAS – X) [44]. In responding to the items of the PSAS, participants were prompted to "describe how intensely [they] generally experience each of these symptoms as [they] attempt to fall asleep in [their] own bedroom". Similarly, in responding to the PANAS-X, participants were prompted to answer considering how they felt at that present moment. During this time, demographic data of age and sex were also collected. Completion of the psychometric battery was done in paper form, in a quiet and comfortable setting within the lab, taking a total of approximately 5-10 minutes.

4.2.2 Inter-Dream Session. Following the completion of the psychometric battery, participants were then introduced to the Inter-Dream system under the guidance of the researchers. This involved explaining that the bed will provide haptic feedback, that sound will be played and visuals will be displayed, with the latter component being modulated by the participants brain activity. Participants were first made comfortable on the bed in a sitting position. The EEG was then fitted, and the participant was prompted to lie down. Regarding electrode placement, recording sites utilized were the TP9, AF7, AF8, and TP10 locations when considering the 10-20 EEG electrode placement system. Once comfortably resting in a lying position, the VR headset was then fitted to the participant, thus beginning the neurofeedback loop. At this time, ambient auditory stimulation was also initiated, sequentially followed by the haptic stimulation of the sleeping platform. At this point, the multisensory experience of Inter-Dream was considered truly initiated and recording of EEG activity commenced. Participants then rested, augmented by the Inter-Dream system, for a total of 10 minutes. At the end of the session, EEG recording was stopped, and participants were gently informed of the sessions end. The VR and EEG headsets were removed, and the participant was given time to adjust to the change in perception before leaving the bed.

4.2.3 Post-Test. Immediately after the Inter-Dream session, a secondary post-test measure of participant pre-sleep arousal and emotional states was made through the implementation of the battery of self-report psychometric scales as conducted in the pre-test phase. However, in this phase, participants were prompted instead to respond to the scale items considering how they felt during their time throughout the Inter-Dream session. Again, completion of the psychometric battery was done in paper form, in a quiet and comfortable setting within the lab, taking a total of 5-10 minutes.

4.2.4 Qualitative Interview. At the conclusion of their involvement in the study, participants were afforded the opportunity to partake in a qualitative interview. This involved open-ended questions on any subjective perceptions, thoughts, and feelings experienced by the participant during the Inter-Dream study. Of the 12 participants of our sample, eight agreed to participate in the interview phase.

4.3 Data Collection and Analysis

4.3.1 Psychometric Scales. Cognitive and mood states predictive of sleep onset were assessed through the pre-sleep arousal scale (PSAS), and the positive and negative affect schedule (PANAS), respectively.

The PSAS is a 16 item self-report instrument designed to assess subjective cognitive and somatic arousal as a state, specifically in the context of pre-sleep [28, 15]. The scale consists of two subscales, somatic and cognitive arousal, with each subscale consisting of eight items. Each item exists as a statement describing a somatic or cognitive symptom associated with pre-sleep arousal (e.g. "Heart racing, pounding, or beating irregularly", "Can't shut off your thoughts"). Respondents rate how intensely they feel each symptom as they normally attempt to fall asleep on a Likert-scale of 1 – 5, with one being "not at all" and five being "extremely". Individual measures of each subscale were made via the summation of responses made to its associated items. Psychometric validation has been demonstrated, showing significant correlation with anxiety, depression and general indices of sleeping difficulty, as well as being able to discriminate insomniacs from normal sleepers [27]. Furthermore, tests of validity and reliability show satisfactory results, with Cronbach's α = .87 and retest reliability = .89 [34].

The PANAS-X is a standardized 60 item self-report scale developed to orthogonally measure levels of positive and negative affect and emotional states. The scale consists of 16 subscales addressing the major emotional and affective dimensions necessary to effectively describe subjective mood states. Each subscale is composed of a number of items, with the summation of that subscale's items being a measure of that subscale. A listing of subscales can be found in table 2. Each item exists as a single word describing an emotion or affect (e.g. "sleepy", "disgusted", "excited"). Respondents rate how intensely they feel each notion on a Likert-scale from 1 to 5, with one being "very slightly or not at all" and five being "extremely". Studies are generally supportive of strong psychometric properties, reliability and validity [40, 26, 10, 38].

4.3.1 EEG Data. The electrophysiological activity indicative of sleep onset was assessed through the recording of EEG data. Fast-Fourier Transformations (FFT) of the raw EEG data are further processed to power spectral density frequency bandwidths allowing for the calculation of absolute power values from which cognitive states can be inferred from. Both the hardware and software discussed have been validated and demonstrated to be viable tools for electrophysiological measurement and research [31, 37].

4.3.1 Qualitative Interviewing. Collection of qualitative data was completed through interviewing [11, 20]. This involved the open-ended discussion of the participants' individual experiential narrative regarding the phenomenon of focus (the Inter-Dream system). Whilst primary guided by the participant, the interviewer facilitated the initiation and sustenance with five prompts. These being: "How would you describe what you just experienced to an alien?"; "How were you feeling or what were you thinking during the beginning of the experience?"; "How were you feeling or what were you thinking during once you settled into the experience?"; "Do you think the experience would have been different if you were using the system alone in your room?"; and "Is there anything else you would like to say?". Interview data were collected via voice recording, and later transposed into text, after which responses were analyzed via thematic analysis.

5 RESULTS

The research design of the study yielded three overarching categories of data. These being: psychometric data, physiological data, and qualitative interview responses. As such data analyses were performed separately for each of these three categories.

5.1 Psychometric Analysis

Preliminary exploratory data analysis was first conducted to obtain descriptive statistics for each subscale of pre-sleep arousal and emotionality measures across pre and post-test conditions. Means, and standard deviations of scale scores are summarized for pre-sleep arousal in Table 1, and emotionality in Table 2.

Table 1. Means and Standard Deviations of Pre-Sleep Arousal Before and After Inter-Dream Experience.

	Pre-Test		Post-Test	
Scale	***M***	***SD***	***M***	***SD***
Somatic	12.75	3.84	11.42	2.96
Cognitive	21.25	8.75	18.67	9.35

5.1.1 Pre-Sleep Arousal. To assess the within subject effect of Inter-Dream on pre-sleep arousal, a series of paired sampled t-tests were conducted comparing pre and post-test scores for each scale. There was found to be no statistically significant difference in the scores of somatic symptoms of pre-sleep arousal between pre-test and post-test conditions ($t\,(1,11) = 1.22$, $p = .25$, $d = .35$). Conversely, there was found to be a statistically significant difference between pre-test and post-test in scores of the cognitive symptoms of pre-sleep arousal ($t\,(1,11) = 3.11$, $p = .01$, $d = .28$).

Table 2. Means and Standard Deviations of Positive and Negative Affect Before and After Inter-Dream Experience

	Pre-Test		Post-Test	
Scale	***M***	***SD***	***M***	***SD***
General Negative Emotion	14.92	4.54	11.75	2.09
Basic Negative Affect	8.81	1.98	7.35	1.16
Fear	10.33	4.19	7.42	2.47
Sadness	8.00	3.59	6.83	2.62
Guilt	8.67	4.31	7.08	2.39
Hostility	9.08	2.47	8.08	0.90
Shyness	7.41	4.25	6.25	3.05
Fatigue	10.00	2.59	8.25	2.56
General Positive Emotion	26.75	7.82	28.83	6.51
Basic Positive Affect	15.67	4.98	16.33	3.62

Joviality	21.17	6.85	22.08	4.52
Self-Assurance	14.42	5.23	15.08	5.52
Attentiveness	10.92	3.09	12.00	2.89
Serenity	9.08	2.11	10.25	2.80
Surprise	5.08	2.19	7.75	2.83

5.1.2 Emotion and Affect. To assess the within subject effect of Inter-Dream on general emotion, a series of t-tests were conducted comparing pre and post-test scores for scales of general positive and negative emotion. There was found to be a statistically significant within-subject decrease in general negative emotion (t (1,11) = 3.25, p = .008, d = .90) after the use of Inter-Dream, while no significant difference was found regarding general positive emotion (t (1,11) = -2.01, p = .07 d = .30).

Similarly, to assess the within subject effect of Inter-Dream on basic affect, a series of t-tests were conducted comparing pre and post-test scores for scales of basic positive and negative affect. There was found to be a statistically significant within-subject decrease in basic negative affect (t (1,11) = 3.64, p = .004, d = .90) after the use of Inter-Dream, while no significant difference was found regarding basic positive affect (t (1,11) = -.76, p = .47. d = .15).

5.2 EEG Analysis

To explore general electrophysiological activity present during the use of the Inter-Dream system, absolute power values were calculated from the power spectral density transformations of raw EEG data, into the conventional frequency bandwidths of Delta(δ) 1-4Hz, Theta(θ) 4-8Hz, Alpha(α) 7.5-13Hz, Beta(β) 13-30Hz, and Gamma(γ) 30-44Hz. Measures of absolute power across time were averaged between participants to demonstrate general trends in cognitive activity across the use of Inter-Dream. This was graphed and displayed in Figure 7.

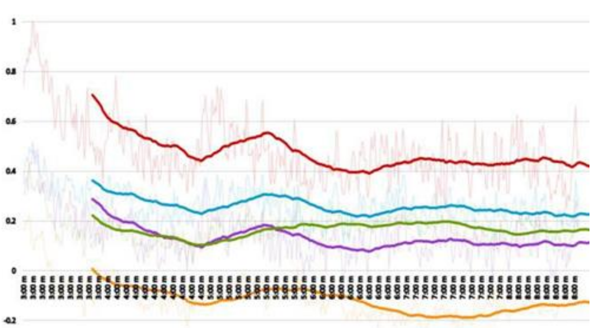

Figure 7: Time series of between-subjects (N=11) mean absolute power for frequency bandwidths delta [red], theta [purple], alpha [blue], beta [green] and gamma [orange].

To further explore which frequency bandwidths were most prevalent by measure of absolute power, a grand mean was calculated from the disparate absolute power means of each participant, summarized in Table 3.

Table 3: Means and Standard Deviations of Power for Each Bandwidth Spectrums Across all Participants (N = 11).

Spectrum	*M*	*SD*
Delta(δ) 1-4Hz	.61	.52
Theta(θ) 4-8Hz	.10	.35
Alpha(α) 7.5-13Hz	.29	.16
Beta(β) 13-30Hz	.21	.24
Gamma(γ) 30-44Hz	.01	.29

5.3 Qualitative Interviews

5.3.1 Passivity and Self-Exploration. Through the participants narrative retelling of their experiences with Inter-Dream, it became evident that there was a pervasive notion of dynamic evolution or progression in the way they interacted with the system. Specifically, they communicated alternating dispositions of passivity and exploration. Most commonly, participants described self-appraisals of passivity when discussing their initial interactions with the system. This was evident in descriptions of "trying to work out what was going on, waiting for it to change" (P4), "wanting to look at all the cool stuff that was happening" (P3), and feeling "kind of passive to whatever was going on and just, see what happens" (P11). These responses demonstrate a degree of initial complacency toward the system, with the participants either attempting to understand its mechanics or perhaps solely appreciating the neurofeedback generated imagery. Nonetheless, these experiences shared commonality in that the participants initially assumed the role of passive external observers.

In conjunction to this, there was a notable shift toward playful self-exploration as participants became habituated to the system. When asked to describe thoughts or feelings after "settling in", participants made statements such as "it was a great space to be exploring your states of mind and how to influence them [...] being with the experience rather than being on the outside"(P5), "I was thinking about things and I could see it was affecting the shape, or I think it was" (P11), and "I was thinking of colors to see if [the graphic] changed" (P3). Furthermore, one participant suggested that "it encouraged introspection, jumping to different thoughts more than usual because it made me a bit more excited about those thoughts … I was more active in them and engaged with them more quickly” (P6). When considered in contrast with descriptions of initial impressions of the system, these statements demonstrate an organic evolution from passive to active interaction with the system. Specifically, this active interaction can be considered as *self-exploration* of the mind.

This was made increasingly apparent when participants were asked if things would be different had they the opportunity to use the system at home. Responses to this prompt included “I would curate the experience a bit more” (P5), “I thought there was a lot of things you could do with it if you got familiar with using it” (P9), and “maybe I could be a bit more genuine with myself … more indicative of my private mind” (P6). Taken together, these narratives suggest a growing interest and engagement in the notion of self-exploration which increase the more familiar the individual becomes with the neurofeedback mechanics of the system.

5.3.2 Mindfulness. Another prevalent theme was the description of cognitive states consistent with those of *mindfulness*. This was often voiced as a redirection of thought away from life stressors and toward the present experience as a result of the systems neurofeedback reactivity. For example, participants stated “I was thinking about my math assignment, and then the introspective nature changed my thoughts on the math assignment, why do I feel the way I do about that assignment […] and they were generally more positive” (P6); “I was trying to clear my mind but I don’t think I really needed to because I was so focused on the imagery because it always changed. There wasn’t much opportunity for my mind to wander off about any problems I had […] And that’s when I thought its sort of a form of meditation because I’m clearing my mind” (P9); “I was drifting off to worries, mainly about work, and it [the change in visuals] brought me out of that” (P4).

In particular, one participant with prior mindfulness experience had much to say in this regard. “I’ve tried mindful activities and found them quite difficult. I tend to fidget. Having this visual focus, but its abstract and doesn’t have any literalness. I think I would find that more useful in helping me relax. Something that is … not like a television that tries to pull your mind in different directions… [but] a kind of peaceful experience that actually acts in the same way that mindfulness is intended to be, perhaps a little more accessible”. (P7) In this case, the participant explicitly draws connection between the system and the act of mindfulness, emphasizing the propensity the neurofeedback driven visual graphic could have in grounding attention to a singular stimuli representative of their own mind.

5.3.3 Restorative Restfulness. A small number of participant responses indicated experiences of restorative restfulness. One participant voiced: “I was expecting it to make me more drowsy, but actually I think I’m more alert and focused”. (P8). This notion was shared with another participant, who expressed that they felt “not less alert but more alert, in a positive way […] I had a migraine. I thought it would make it worse, but I think it made it better” (P4).

5.3.4 Neurocentric Agency. Participants were also prompted to explain the experience of Inter-Dream as a “thing in itself”. This was done by asking them to explain it as if they were describing it to an alien, implying to reduce it down to its most fundamental components. This prompt was intended to discern what components of the system the participant deemed most important to the experience. In response, there was an overwhelming focus on describing the connection between the visual imagery, and their brains activity. This was communicated in that participants described Inter-dream as: “Brain activity represented as artwork… a creative image of brain activity that looks like art”. (P3); “Some type of artistically imposed hallucination or art form of a visual hallucination, in a way connected to what you were thinking”. (P4); “A creative experience involving stimuli to inflect a state of consciousness”. (P5).; and “I saw patterns and colors of my thoughts” (P9). As the focus of these responses is directed towards the elements of the system that the participant had agency over through the brain-computer interface, we describe this theme as *neurocentric agency*. In addition, these responses also suggest the participants saw this *neurocentric agency* as a form of artistic or creative expression.

This notion is further reinforced by responses from later stages in the interview, where participants were given the opportunity to make suggestions, or voice opinions they thought important. Participants stated that: “Although there were different positions with the bed I don’t know if I controlled it… I think the vibrations were distracting”(P9); “I was confused as to whether the bed was changing as a result of what I was thinking […] Was it planned or did I do that?”(P6); “I was thrown off a bit when it went bright red, it was like looking into the eye of Sauron”.(P8); and “I felt that the music was separate to the experience and not being engulfing”. (P5). What unites these responses is that they all address components of the system that the individual had no *neurocentric agency* over, a phenomenon that was typically met with confusion or a perception of broken cohesion in the system.

6 DISCUSSION

Here we provide discussion considering the results gathered from each of the three perspectives of our analyses and provide design strategies for applicating these findings.

6.1 Arousal, Emotion and Affect

The results of our psychometric analyses regarding measures of pre-sleep arousal demonstrated a statistically significant decrease in pre-sleep cognitive arousal when participants rest was augmented by the Inter-Dream system, whilst no significant change was seen for pre-sleep somatic arousal. Similarly, results also suggested participants experienced a significant decrease in negative mood and affect while resting with the Inter-Dream system, but no significant difference in measures of positive emotion and affect.

Together, these findings suggest that the experience of Inter-Dream partially induced the psychophysiological pre-sleep states necessary for sleep onset. This would indicate that participants experienced a decrease in chaotic, invasive, or hyperalert thoughts and worries; while the prevalence of irritating or distracting bodily sensations would have been consistent throughout. Additionally, participants experienced a negation of negative thoughts or feeling they had prior to entering the system, all the while not necessarily experiencing any elation or excitement as a result.

Possible explanations for the within-subject consistency of somatic arousal are twofold. Firstly, the initial mean of the pre-test condition was quite low (M = 12.78), being quite close to the minimum score the scale could possibly yield (M = 8). As a result, an expectation in any notably further drop in mean than what was witnessed yielding a significant result would not be likely. Second, and perhaps most likely, was the notion that there was a physical element of the system which participants found irritating, uncomfortable or distracting. This idea is supported by the participant interviews, with responses commonly reporting the feeling that components of the system they had no agency over were either distracting or detached form the experience.

6.2 Electrophysiology

Neural activity by measure of EEG absolute power spectral density produced results largely consistent with the literature's description of neural activity during healthy sleep onset. This was most evidently seen in the high power level of the delta frequency bandwidth relative to others, which is a defining characteristic of sleep related activity [28].

The observed trend in the alpha power level across time was not consistent with that described in the literature [28]. While it would be expected for alpha to drop dramatically toward the later stages of sleep onset, visual inspection of plotted alpha values over time suggested no such activity. However, considering the relatively short timeframe of Inter-Dream sessions, and that no participants reported falling asleep during their session, the absence of an alpha drop would be expected.

6.3 Design Strategies

In considering the findings of our study, we propose a series of design strategies. These are intended to guide designers and artists in designing neurofeedback systems to promote positive sleep through the augmentation of pre-sleep.

6.3.1 Tactic 1: Facilitate Exploration. Through the study of our system we have identified a set of mechanics that can facilitate playful exploration even in physically passive contexts, such as those of pre-sleep or sleep. This was arguably achieved through framing the subject of the exploration as none other than "the self", something that is perpetually dynamic in an otherwise static environment. Consider that the mind only stops moving when it's dead. It is through the lens of this concept that we propose neurofeedback or brain-computer interfacing as powerful tools for bringing interactivity to a passive setting.

Furthermore, participant responses demonstrated a disposition of curiosity toward the depth of exploration the system allowed, stating their desire to take the system home, curate the experience, experiment with it, and use it to better understand themselves. With this considered, we propose it would be in the interest of designers developing interactive neurofeedback systems to expand on the level of variability and uniqueness that can be achieved with subsequent or prolonged use, to reward that exploration. We suggest this could be achieved by increasing the amount of biometric input the system is responsive to (more electrodes, or different biosensors), creatively using EEG feature extraction methods to produce unique output in specific circumstances or increasing the number of parameters that can be modulated through the brain-computer interface.

This concept builds upon the findings of Kitson, et al. [24], in their exploration of introspective VR as a tool for lucid dreaming. The authors state that abstract spaces such as those experienced in lucid dreams provide opportunity for the development of personal meaning, in turn exploring one's thoughts and feelings, whilst also being playful to encourage said exploration. However, while the authors state this is yet to be put into practice in interactive technologies (which are typically led by the designer), the present study demonstrates the capability of affording such experiences through the playful artistic abstraction of neurofeedback, within the context of pre-sleep.

6.3.2 Tactic 2: Promote Neurocentric Agency. The prevalence of the theme of *neurocentric agency* suggested that in a multisensory neurofeedback or brain-computer interface driven system, individuals are more inclined to engage with and appreciate stimuli or components which they have agency over. Participants voiced opinions of feelings of disconnect or disparity between the components of the system not responsive to their thought. This also manifested as confusion as they attempted to manipulate non-responsive components, not understanding those stimuli were separate to the brain computer interface. With these points considered, we propose that the future design of multisensory neurofeedback driven systems should consider avoiding the inclusion of non-reactive elements as core components of the experience.

Again, this resonates with the sentiment proposed by Kitson, et al, [24] who propose users should feel a sense of control in order to generate feelings of empowerment and confidence that can be carried into the real world when designing for lucid dreams. Through neurocentric agency we demonstrate that this can be achieved to the broader application of pre-sleep, through the implementation of neurofeedback systems where the major parameters of the system can be controlled by the user's mind.

6.3.2 Tactic 3: Facilitate Self-expression. Furthermore, this appreciation of agency was often paired with appraisals of artistic creativity toward the system. This illustrated the notion that participants appreciated the degree to which they could fluidly create through expression of their, in all other circumstances, private electrophysiology, their consciousness. As such, we recommend the exploration of means in which users can interpersonally express and share their creativity generated by electrophysiological output. This could be further fostered by, for example, designing toward the integration of multiple users in a neurofeedback driven system, thereby providing a means for sharing and mutually appreciating the individuality of mind.

6.4 Limitations

One limitation of the study, specifically when considering its situation within the broader context of sleep, was the design choices present due to the systems origin as a public interactive art installation. Accordingly, some components of the system, namely the use of VR, while suitable in the domain of pre-sleep, are not entirely compatible with sleep itself due to the unwieldly nature of the HMD. As such, while the use of VR assisted in demonstrating that neurofeedback driven artistic expression and creative exploration may promote positive pre-sleep states, the findings of our study cannot be generalized beyond pre-sleep.

Similarly, the study's research design did not directly measure the promotion of sleep quality directly, but rather inferred the potential for interactive technologies to improve sleep through its positive influence on pre-sleep. With this considered, abstracting the findings of the present study beyond pre-sleep should be approached cautiously, as research directly assessing the influence of interactive technology on sleep quality must first be preformed before it can be claimed with confidence that systems such as Inter-Dream can indeed promote sleep quality.

Further limitations of this study's design include the lack of a control group. The addition of a control group who were exposed to similar conditions (i.e. rested in a bed in the laboratory) but did not experience the Inter-Dream system would have allowed for a more detailed between-group analysis of electrophysiological activity.

Finally, the interactivity of some of Inter-Dream's components (i.e. the bed and audio) were operated by the artists. With this considered, having a fully automated system driven completely by neurofeedback could potentially reveal more detailed or unique insights.

6.5 Future Work

The results of our study demonstrated promise in the application and development of technology for the induction of positive pre-sleep. With this considered, there is room to argue that we have highlighted an avenue of further inquiry for sleep researchers or psychotherapists designing interventions for promoting sleep health through neurofeedback facilitated creative expression and playful exploration. However, consideration of the limitations discussed above highlights two important research problems that must first be addressed. Firstly, alternative media to artistically represent neurofeedback in an Inter-Dream-like system must be explored in order to overcome its present incompatibility with true sleep. Namely, alternatives to VR must be considered. Similarly, to move beyond pre-sleep, future research designs are encouraged a more direct assessment of the interaction between Inter-Dream like systems and sleep quality, if such systems are to be implemented as a tool to specifically promote sleep health.

7 CONCLUSIONS

In this paper, we acknowledged the increasing global health concern of poor sleep and propose that technology holds potential addressing this issue through the augmented promotion of healthy sleep. We began to explore this potential by first operationalizing variables detrimental to sleep into a set of physiological and psychological states. We then identified how existing research has worked to address these variables through the implementation of sleep technology, either directly or indirectly. Taking inspiration from these approaches, we then proposed Inter-Dream, a neurofeedback driven multisensory artistic experience, and explore its potential to induce pre-sleep psychophysiological states necessary for the onset of sleep. We assessed this potential in a user study, in which Inter-Dream is illustrated to be capable in inducing many of the psychophysiological pre-sleep states promoting sleep onset, while also crafting design strategies from interview responses. Taken together, our work highlighted the potential of neurofeedback technologies to facilitate creative expression and playful exploration as a potential pathway for future research in supporting sleep, while also suggesting design strategies informing how this can be achieved specifically within the context of pre-sleep.

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