Dormio: Interfacing with Dreams

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Abstract

Current HCI research overlooks an opportunity to create human-machine interaction within the unique cognition ongoing during dreams and drowsiness. During sleep

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onset, a window of opportunity arises in the form of Hypnagogia, a semi-lucid sleep state where we begin dreaming before we fall fully unconscious. To access this state, we developed Dormio, the first interactive interface for sleep, designed for use across levels of consciousness. Here we present evidence for a first use case, directing dream content to augment human creativity. The system enables future HCI research into Hypnagogia, extending interactive technology across levels of consciousness.

Author Keywords

Dreams; Creativity; Sleep; Hypnagogia; Interfaces; Social Robots; Biometrics.

ACM Classification Keywords

J.4 Social and Behavioral Sciences: Psychology; H.5.2 User Interfaces: Voice I/O; K.4.2 Computers and Society: General; I.2.9 Robotics.

Introduction

"There is a class of fancies, of exquisite delicacy, which are not thoughts; they seem to be rather psychal than intellectual... I am aware of these 'fancies' only when I am on the brink of sleep, with the consciousness that I am so...it is a glimpse of the spirit's outer world...the delight experienced has, as its element, but the absoluteness of novelty" Edgar Allen Poe [30]

Figure 1: Flow diagram of Dormio's system components

Sleep is a forgotten country of the mind: though we spend nearly a third of our lives asleep, we build interfaces exclusively for the awake state. We are left with no way to exchange information with our unconscious or semi-conscious selves, failing to make active use of our nightly altered cognition. By popular account, thinkers August Kekulé, Thomas Edison and Nikola Tesla all regularly napped with a steel ball in hand: As they lost consciousness and muscle control, they were jolted awake suddenly as it fell to the floor below [42]. A dive into the humanities reveals use of this technique by artists as well, from Nabokov to Mozart to Poe [24], [29]. Artists and scientists alike used this crude but fascinating technique to awaken during sleep onset, unearthing creative inspiration found in fragmented dreams on the threshold between drowsy stage 1 sleep and fully unconscious stage 2 [28]. This semi-conscious state, called Hypnagogia, is characterized by phenomenological unpredictability: visual and kinesthetic hallucinations, spontaneous words, distorted perception of space and time, awareness of sleep onset and loss of sense of self have all been reported [29], [25]. Unlike other dream states allowing for awareness, namely REM-state lucid dreaming, Hypnagogia is a typical stage of circadian rhythm, extremely common across subjects and requiring no training [29]. The system described in this paper, Dormio, offers an interface to this liminal state of mind: We present results suggesting feasibility of dream interfacing as well as overall satisfaction and comfort with the system.

This paper primarily makes the following contributions: Dormio represents the first interactive interface built for sleep, modernizing past techniques for dream influencing which have ranged from steel balls to yoga mantras. Dormio opens up many possible use cases for

building future dream interactions as evidence suggests the system is able to extend, control and extract information from the hypnagogic sleep state. Based on our results, we contribute a technological mechanism capable of extending typical sleep stages and carrying conversations across levels of consciousness. Secondly, this paper offers evidence for augmentation of awake creativity [6] by directing dreams and recording dream content reports, offering a first use case for our proposal of sleep HCI. We hope this paper introduces the HCI community to Hypnagogia and to the larger sleep neuroscience literature, ripe with opportunities for HCI.

Related Work

Intervening in Sleep

Research shows 9/10 Americans report using a technological device in the hour before sleep [15]. Yet much HCI research has focused on sensors for tracking sleep, with less focus on interventions encouraging healthier sleep or making use of sleep cognition [32]. Form factors for sleep tracking range from wearables on the wrist to mobile apps and smart pillows, presenting many opportunities for future interaction designs [22].

Sleep interventions that do attempt to influence or enhance cognition mainly focus on REM sleep. Essence, a wearable system, showed the possibility of introducing odors in REM sleep nightmares to aid in trauma reappraisal [3]. Current stimulation in the gamma band during REM sleep increases self-reflective awareness in dreams [39]. Magnetic stimulation and pink noise have been shown to be effective in manipulating sleep depth, aiming to increase sleep efficiency [23], [37]. Previous HCI research has explored interaction design opportunities around supporting sleep transitions and

Figure 2: Dormio's tracking glove uses Arduino-based force sensing as a measure of muscle control. We acknowledge Sophia Yang for assisting with glove design

efficient sleep, highlighting the need for scheduling sleep to optimize circadian rhythm [1].

Much of this work relies on successful detection of sleep stages using EEG classification. Reliable classification of sleep stages with complex, expensive polysomnograms using brain and biosignals has been demonstrated for decades in sleep neuroscience labs. Recent work from the HCI community has shown it is possible to reliably classify sleep stages with only 2 EEG electrodes, if they are placed inside the ears [27]. Recent research has also shown correlations between spindle power and creativity, suggesting a target biomarker for future HCI systems using sleep to augment awake creativity [7].

Exploring Creativity

Creativity is an altered state of mind: in a moment of invention, “the creator breaks free of logic and deductive reasoning, of familiar pathways, of taken-for-granted approaches” [20]. Decreased inhibition has been shown to greatly help this creative idea generation [31]. Much HCI work has focused on facilitating the ideation that comes before execution of a creative task. Applications like *IdeaExpander* aim to enhance communal creativity, displaying conversationally triggered images in an online chat-room to enhance group brainstorming [43]. *Momentum*, a web-based tool that elicits on-topic responses before a group brainstorm, helps people stay on topic during creative ideation [5]. While these brainstorming techniques represent significant creativity augmentations, ideation in the awake state is always seriously limited by inhibition resulting from fear of personal and social criticism of extremely original, and often aberrant, creative ideas [5].

Sleep offers clear creative opportunities. EEG and fMRI work has shown that the same hypofrontality underlying

creative flexibility while awake is also common to the early stages of sleep [37], [14]. REM sleep has been shown to enhance the integration of unassociated information for creative problem solving [29], [10]. Hypofrontality in sleep thus provides possibilities for creative idea generation in hypnagogia, if novel thoughts can be captured. As such, HCI creativity augmentations can benefit from past work detailing challenges in spurring creative ideation while awake and opportunities for ideation within Hypnagogia [5], [29].

System Implementation and Affordances

Muscle Control Detection

Before going to sleep, users put on the Dormio glove. Given that people lose muscle control when entering stage 2 sleep [42], we designed an Arduino-based glove to signal to the Dormio system when users are no longer able to hold a closed fist. With an embedded force sensitive resistor in the palm, users can comfortably touch the sensor during their wakeful state and send a signal of ‘no-touch’ back to the system upon sleep onset when their hand opens and force ceases. Figures 2 and 3 show the design of the glove used in our experiments.

Auditory Feedback on Sleep Stage

With a constant feed of data on muscle control tied to a conversational robot, Jibo, Dormio alerts users whenever they enter unconscious stage 2 sleep, so they do not go deeper into sleep stages 3, 4 or REM. To do this correctly, Dormio must prompt users, saying “[Name(x)] you are falling asleep” at the correct time and correct volume—not missing Hypnagogia by prompting either too early, too late or too loudly. Dormio reliably instigated multiple bouts of Hypnagogia and prevented descent into deep sleep in 6/6 of our subjects, successfully extending the standard experience of Hypnagogia.

Figure 3. Multisensory changes in perception during experimental condition as reported by subjects

Inception and Conversation

Dormio is next able to speak with users in Hypnagogia about any pre-programmed prompt, using either text-to-speech generation as was done in the current experiment or a pre-recorded audio cue. After alerting users they are falling past Hypnagogia into deeper sleep, Dormio says "remember to think of [dream cue (a)]", then "tell me, what are you thinking about" and finally "can you tell me more?", with a 2-minute delay between prompts. In 6/6 of our subjects this instigated reports of microdreams about the prompt word, either "a rabbit" or "a fork".

Audio Data Capture

As subjects respond to prompts, Dormio is recording any audio of sleep-talking as well as muscular and EEG data. This is important for a take-home system as subjects remembered most, but not all of their conversations with Dormio, and can later review data.

Portability

The simplicity and portability of the Dormio system means casual users or researchers can easily use Dormio for idea generation at home or in the laboratory, programming in prompts about whatever they want to brainstorm about.

Sleep Detection Via EEG

We propose a preliminary algorithm for sleep stage detection with our MUSE EEG dataset. EEG data has been used as a reliable measure of the depth of drowsiness, with sleep spindles marking the end of Hypnagogia and beginning of unconsciousness [29]. Given that EEG data from the MUSE tends to be noisy, and available spindle detection algorithms are designed for 32+ EEG channels, we were limited in using sophisticated methods to detect sleep spindles. Hence,

we propose a preliminary algorithm that uses a variety of existing techniques. In particular, we draw from Molle [26] and Devuyst [12]. We use data from EEG channel TP-10, located behind each subject's right ear. The algorithm uses a band-pass filter with cutoff frequencies from 9-12 Hz and subsequently computes the Root Mean Square (RMS) value RMS_{9-12} of the filtered data with a short overlapping moving window of 100 milliseconds. The algorithm also uses a band-pass filter from 0.5-40 Hz and computes a similar RMS value $RMS_{0.5-40}$ with a moving average window of 1 second. Spindles are now detected by thresholding the $\frac{RMS_{9-12}}{RMS_{0.5-40}}$ value, and looking for a consistent detection for at least another 1 second. Thus, the algorithm takes two parameters: threshold of parameters values and the number of seconds after which the algorithm discards spindles. The algorithm discards any detected spindle that lasts more than 2 seconds as spindles are known to last approximately .5 to 1.5 seconds [26]. We conducted a pilot study to test this algorithm, in which we only detected spindles after Stage 2 onset as measured by loss of muscle tone.

Experimental Materials and Methods

Method: Field Experiment

We enrolled 8 graduate students (4 male, 4 female) from the Greater Boston Area as participants for a within-subjects design experiment. The average age of the participants was 23.8 yrs (SD 1.76). Participants arrived at the laboratory in the evening (between the hours of 5:00 pm and 9:00 pm) and were instructed to lie down in a testing room bed. Participants were told the test was investigating the relationship between rest and creativity, and that they would engage in both active rest (lying down awake with eyes closed) and sleep. Experimenters remained in the room with subjects for safety, staying out of sight behind a partition wall after subjects lay down, and returned to

	Control avg.	Experimental avg.
Subject 1	2.225	3.25
Subject 2	3.515	2.465
Subject 3	3.3	3.55
Subject 4	2.33	2.35
Subject 5	2.495	2.965
Subject 6	3.205	3.315

Table 1: Alternative Uses Task (AUT) results. Subjects (n=6) were tested on the AUT for divergent thinking. Subjects highlighted in green show higher average ratings after the experimental condition.

Subjects	Control	Condition
s1	255	524
s2	268	333
s3	440	628
s4	656	774
s5	312	575
s6	298	348

Table 2: Time spent in storytelling task post experimental and control conditions. Subjects (n=6) spent an average of 158.8 seconds (SD 87.7 seconds) more time expressing their creative story after experimental condition.

deliver instructions after wakeup. Subjects were informed that upon wakeup with prompt words they could experience something akin to hallucinations and should not worry, simply stay calm and still and inform experimenters of any discomfort. Prompt words for each condition (either “A Rabbit” or “A Fork”) were matched based on their values of affective arousal, according to the Affective Norms for English Words [8]. Words were further counterbalanced with conditions, such that no consistent word-condition association could skew results. Two participants (both male) were not tired enough to fall asleep during the experimental condition. Their data is excluded from our analysis and results. The experiment took 2 hours from start to finish.

In the control condition (n=6) of active rest, participants were asked to answer a pre-condition survey, lay down with their eyes closed, remain still and awake and think of a given prompt word for a span of 8 minutes. Participants were asked to focus on any ideas or images that came up while lying down. While laying down, the participant was prompted three times by the robot on what word to think about (“remember to think of a rabbit/fork”), matching number of prompts across conditions. Once 8 minutes ended, the robot asked participants to open their eyes and participants were given pen and paper. Participants were then presented with the Alternative Uses Task (AUT) [17], a classic test of creativity, and given 2 minutes to write alternative uses for the specific word they were prompted with; i.e. alternative uses for a fork. Participants were then asked to tell a story using the prompt word. Participants were informed that there was no time deadline for this task, but an alert would be provided after 5 minutes of writing, and that they could make use of any media they preferred (drawing, writing). Total story writing time was recorded across both conditions.

For the experimental condition (n=6), participants repeated the same protocol but were wearing the Dormio system and were instructed to fall asleep. Participants were asked to focus on any ideas or images that came up while lying down. Once the robot prompted them to go to sleep, the system started tracking the participant’s hand pressure over the FSR sensor, as well as recording EEG signals. Once a loss of muscle control was picked up by the system, a 3-minute timer was triggered after which the robot would alert participants they were falling asleep. This 3-minute window was chosen to ensure full sleep onset transition, and because previous work with serial awakenings has shown hypnagogic imagery can continue into early stage 2 sleep [28]. Within this 3-minute window, the system continued EEG data capture and tracking sleep spindles. After alerting participants of sleep onset, the robot reminded the participant to think of the prompt word, asked them to vocalize the thoughts they were currently having, and recorded audio. Once subjects finished speaking, the robot instructed them to hold the glove again and prompted them to go back to sleep. This loop of events was repeated three total times in order to confirm the system enabled entering and exiting unconsciousness multiple times. At the end of the last loop, the robot instructed the participant to wake up fully. Immediately after removing the Dormio system, participants were tested again using the AUT test, as well as asked to write up a story in the same way they did in the control condition.

Scoring Creativity

Scoring Alternative Uses Task (AUT)

To score creativity of idea generation in the AUT test, we replicated scoring methods from the clearest comparable paper to ours [34]. In this study, researchers investigated creativity augmentation in REM sleep, and

"The story I wrote about the rabbit based on what I experienced in the microdreams seems less restrained than what I would usually write about. I stepped out of myself. Ideas were not coming from me, they were just passing through my head. I could be reflective and sort of coherent while also being in this state of I'm not really here...I really wanted to do it again...I felt like I could be addicted for a second. I was not wanting to let go of being out of my own way...it was very similar to when if I'm meditating...this sense of not really being in the room. I felt I was nowhere really, in this kind of nowhere space where all these ideas exist, and it made so much sense that all these ideas existed in this nowhere space."

Figure 4: Subject 1 describes the experience of creative story writing immediately after arousal from Hypnagogia.

relied on an AUT to assess creative idea generation. Following this model, two human raters were trained with an elaborate explanation of the concept of creativity, centered around novelty of ideas, and the raters were provided with information about the scoring system. Each rater then performed a 10-minute practice phase with feedback. Each list of Alternative Uses was assessed by 2 trained raters. None of the authors of this paper were raters and raters did not know about the experimental design. Each rater scored the creativity of each individual items on a five-point Likert scale (from 1 = 'not at all creative' to 5 = 'extremely creative'). For the AUT the measure of interest was each participant's average creativity score (mean rater score/number of uses listed) independent of number of ideas generated.

Scoring Creative Story

Unlike the AUT, which is grounded in decades of creativity research, no comparable study or obvious metric was seen in the literature to score creativity for each story generated. We thus decided to rely on proxies for creativity. We measured whether subjects used mixed media in stories in either condition, as multimedia learning and expression is tied to creativity [19]. We also measured in which condition participants told creative stories for more time, as intrinsic motivation and enjoyment of storytelling has been shown to significantly increase creativity in writers [2].

Results

Enabling Hypnagogic Dream Access and Inception

The primary objective with this study is to demonstrate a successful interface for accessing hypnagogic cognition. 100% (6/6) of our subjects remembered and reported seeing the prompt word during their dream state, showing successful inception and recall of stimuli into said dream state. This allows subjects to actively

reflect on their semi-lucid Hypnagogic cognition, allowing for a 'conversation' across levels of consciousness detailed in verbal reports. Each subject had 3 recorded losses of muscle control, prompting 3 audio cues from Dormio, showing multiple entrances to and from unconsciousness. 83.33% ($\frac{5}{6}$) of the participants reported an emotional experience in hypnagogia, and 83.33% ($\frac{5}{6}$) reported an intellectual experience in hypnagogia. Though prompting was exclusively in audio, thematic hypnagogic experiences were multisensory.

User Experience with the Dormio System

Subjects rated their comfort with the conversational interface on average 4.5/5 (SD.5), from 1 "uncomfortable" to 5 "very comfortable", while two subjects noted that the presence of researchers supervising in the room, made them less comfortable. It is further important to note that 2 subjects commented that keeping their hand closed for force sensing made falling asleep more difficult, and that they found the robotic voice had a jarring tone. These reports open up opportunities for future interaction improvements.

Creative Augmentation

Our secondary objective was exploring the use of the hypnagogic state for augmenting creativity. Creativity is so multidimensional: Different definitions of creativity factor in a range of assessors including divergent thinking, desire for novelty, or abstractness of thought [11]. As such, creativity as a whole has proven difficult to measure objectively since its study became mainstream in the sciences in 1950 [36], [16]. Incubation and reductions in inhibition both improve divergent thinking specifically, making it a good target for augmentation in hypnagogic periods [31], [33]. We expect future testing with the Dormio interface will

"I felt that my thoughts and feelings flowed more freely, or rather I was able to go from one set to another without as much inhibition as I normally would. I would be reminded to think of a rabbit and each time was like the new beginning of a story with very different rabbit characters. For example, my childhood pet rabbit, an aluminum rabbit head, a dissected rabbit, a warren of rabbits thumping the ground rhythmically. I definitely feel my microdreams were drawing from the emotional experiences I was undergoing, whether it be isolation of being far from home, which translated as a rabbit floating in the water on macaroni cheese, which I was craving. The thumping of feet came from sounds I was hearing. The prompt by Jibo drew me back to the thought of a rabbit, as my thoughts would segue to other subjects."

Figure 5: Subject 1 describes the translation of awake sensations and stimuli into the hypnagogic dream state

narrow down exact pros and cons for use of Dormio within these many multidimensional creativity metrics. As creativity is both a subjective and objective phenomenon, we take seriously both self-report on creativity within the Dormio system experience [35] and objective measures of creativity.

Alternative Uses Task test results

As mentioned, we used methods from Ritter (2002) [34] in order to evaluate subjects' answers to the AUT task. Table 1 shows scores across both raters across conditions and within subjects. Average ratings showed responses given in the experimental condition to be more creative for 5 out of 6 subjects.

Story Results

6/6 subjects wrote stories for more time after hypnagogia, with an average increase of 158.8 seconds (SD 87.7 seconds), understood as a proxy for motivation and enjoyment of creative storytelling. 4/6 subjects expressed their story in mixed media (drawing and writing) after hypnagogia, versus 6/6 choosing to use only one medium (writing) after the control condition. We take the above statistics as proxies for increases in creativity, and recognize the lack of standardized measures for creative story assessment as an opportunity for improvement in the field. While it is not within the scope of this paper, our future work will undertake the write-up and analysis of experimentally engendered dream content.

Creativity Self-Assessment

3/5 subjects reported feeling less inhibited during hypnagogia (1/6 did not answer this question). 4/6 subjects saw ideas generated in Hypnagogia as creative.

Limitations and Future Work

We observe successful interaction with hypnagogic states with our Dormio system, yet our limited number of subjects (n=6) is worth noting. Studies that require napping and take 2 hours are difficult to recruit for, but it is necessary to expand this work into a larger subject set. This will allow for further validation of the system as well as collecting and train data to build a model. While these results are encouraging, we will extend this work in both size and scope, incepting more varied prompts ranging in abstraction and provocation amongst a more diverse corpus of subjects.

While our subjects reported comfort with our system, our study presents a number of opportunities for improvement. Having to press the FSR sensor made it more difficult for some subjects to fall asleep: New muscle tone tracking mechanisms are needed. Subjects reported perceiving the voice of the robot as disruptive at times. Although we recognize this system could be implemented in other interfaces, and it is fully working on a cell phone, we believe the idea of an embodied social robot dream companion that can interact with the user pre, post and during hypnagogia is a compelling vision. Sleep HCI comparisons between social robots and other interfaces must be designed to evaluate this hypothesis.

Further, while we are able to algorithmically track EEG spindles in Subject 1 without false positives, we have not shown this detection algorithm generalizes across subjects. To make a generalizable spindle detection algorithm we need far more MUSE EEG data from each sleeping subject, which is why we prioritized EEG data gathering over intervention for this study. We have shown we can successfully induce and influence the hypnagogic state using only atonia related muscular

"It was slimy when the rabbit entered this world it was slimy and slow and there was splashes of colors like smoke and it was in Italy with very bright white houses in the village. And the mountain started growing and he was on top of it and he jumped in the emptiness. First it was the sea of water but then it turned into a forest and it kept falling into the void. But that became flying and the sharks moved from right to left by saccades. One,... Two,... Three,... and its shape changed into a knife but it was ok. The spiked started growing while a dark wall of glass appeared before his eyes and the wall became his eyes and someone on the other side was using a drill to pierce holes but then it became gelly and then bright again. He kept falling horizontally. And the sky became the bones inside a ribcage and then he understood."

Figure 6: Story written by subject 8 immediately after arousal from Hypnagogia

data, but in future work would like to use EEG to investigate and intervene with precision on the 9 stages of drowsiness distinguishable via EEG [28].

Conclusions

Interface

Dormio represents the first interactive interface built for sleep, able to instigate and interface with hypnagogia, control dream content based on pre-programmed prompts, and capture and extend hypnagogic cognition. We hope the possibility for information exchange between waking and sleeping cognition with Dormio, as with any new interface, inspires new experiments and applications. We modernized the 'steel ball technique' to create an open and exploratory microdream interface, the first of its kind. We hope evidence of Dormio's efficacy encourages HCI researchers to push future work across levels of consciousness.

Creativity

For such a crucial part of our personal and professional lives, creativity remains deeply difficult to understand and even more difficult to reliably prompt. Preliminary experimental evidence suggests Dormio can augment human creativity as measured by the Alternative Uses Task, creative storytelling task and subject self-report. Evidence of increased divergent thinking, increased motivation in creative cognition and decreased inhibition in Hypnagogia by Dormio users suggests this interface is a possible tool for creativity augmentation. Coupled with the success of the Dormio interface, namely the consistency with which thematic prompts enter dreams, Dormio may represent a reliable interface to prompt specific, thematic creative cognition and make active use of an otherwise overlooked state of mind.

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