Designing for the State of Flow in Immersive Digital Experiences

By

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Abstract

The popularization of virtual reality (VR) and augmented reality (AR) applications gives designers and developers tremendous opportunities to shape the evolution of new interaction paradigms. Current human machine interaction models are built on top of the command and control metaphors dating back to the industrial revolution, where input has to be initiated with user's full conscious thought in a non-parallel and discrete manner. Further, many people experience the adverse side effects of software products that are designed with the goal of increasing engagement. Mental states like email anxiety are driving down the wellness and productivity of the general population, and as VR and AR devices replace our physical spaces with digital experiences, these problems will become far more serious.

This thesis explores methodologies for designing to promote the state of Flow through VR and AR experiences that bring interactions with virtual information closer to how humans consciously and subconsciously perceive, process, and interact with the real world. Designing interfaces to promote the state of Flow has several benefits. First, it requires interfaces to respect people's focus, which increases productivity and quality. Second, Flow has been shown to give people a sense of enjoyment, leading people to feel happier and more fulfilled. Drawing on research suggesting that encouraging the characteristic expressions of Flow such as focus and an implemental mindset can help induce the Flow state, the thesis explores techniques VR and AR applications can use to promote the state of Flow and overall wellbeing through the design of their interfaces.

Thesis Supervisor: Pattie Maes

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Chapter 1

Introduction

1.1 Motivation

From room sized computers and the first graphical user interfaces to laptops, mobile devices, and virtual or augmented reality headsets, our interaction paradigms haven't moved far from their abstract, symbolic origins. We rely on indirect input modalities such as mice, track pads, and keyboards as the primary method of interacting with computers. These input methods are deterministic and non-parallel which makes them fundamentally non-humanistic, and leave us missing a huge spectrum of interactions with the world, from direct tactile manipulation to emotional expression. While touch screens and voice interactions are making interfaces more direct and apparently more human, they still lack the rich feedback of the real world, such as conversational interaction, tactility or the rich non-verbal acknowledgement people use while communicating known as back channeling. We talk about a human centered approach in the context of user interface design while missing most of the ways humans interact with each other and with the world.

Current interaction paradigms are flawed because they simultaneously demand high cognitive workload while limiting people's capacity to fully utilize their abilities to interact and communicate, setting people up for frustration and cognitive overload. These abstracted command and control paradigms require our conscious effort at all times, every input the computer gets has to be initiated by a person translating what he or she wants into an action recognizable by the computer. The translation process not only puts stress on people's cognitive capacity, but it is also inherently non-parallel since people are only able to input one command at a time. Furthermore, the computing devices we carry with us everywhere do not adapt to our cognitive load, mental capacity, our emotional states, and our social contexts. They force us to conform to their rules, and limit our ability to live in the moment and enjoy what we are doing or even just focus on a specific task. While computers are incredible tools, the constant digital clamor for attention they allow often drives people into a state of distracted multi-tasking that reduces productivity and overall wellbeing.

The computing devices we use today meet a lot of our functional needs, which is why we have been tolerant of their rigid and non-humanistic interfaces, but as virtual experiences become increasingly pervasive, the negative repercussions of designing for inattention are becoming increasingly obvious. Constant notifications distract people from whatever they are actually trying to do, whether that is analyzing experimental data, talking over dinner, or driving. As computing devices enter every aspect of our lives and the digitally mediated experiences they allow become increasingly pervasive, the threats caused by poorly considered user experience decisions are very real and immediate.

Until very recently, people's interactions with computers were confined largely to handheld or stationary screens, and the spaces people inhabit have remained largely separate from the virtual or digital world. With the recent proliferation of virtual reality (VR) and augmented reality (AR) devices however, we are seeing a new kind of personal computing revolution, one that could merge our personal space with computing space entirely. If we simply apply the same interaction models we have used with screen experiences to AR and VR interfaces, we will miss out on a lot of the potential these technologies could unlock, and the gap between our virtual interactions and our abilities to engage with the real world will widen substantially. We could easily end up with a reality where all we have control over are one or two of our fingers. This is the kind of future our command and control interface paradigm promises. Further, the buffer that confines virtual experience to screens will vanish, and the distracting clamor of badges and notifications that applications use to attract people's attention and push up engagement could become even harder to ignore. Many of the current software product business incentives could push us towards the sort of dehumanizing and overwhelming future shown in Keiichi Matsuda's short film HYPERREALITY.

While bad experiences tend to get sorted out or abandoned eventually, once interaction patterns get established, they can often be very difficult to dislodge.

People cling on to poorly designed operating systems even if they have access to better options, simply because they are used to the way the old system works. This means the decisions made when a technology or category of products is introduced can have a lasting impact on its developmental trajectory. For AR and VR, what we design at this moment in the history of head mounted device interaction design, whether good or bad, could become the "intuitive" solution of the future. We have the responsibility to do our future selves and everyone else a favor by designing with fundamental human capabilities, needs, and desires in mind.

What can we do today to start building a new interaction paradigm that can address the challenges of information overload and distraction while scaling into an increasingly immersive digital future? First, leveraging the full range of human capabilities for input and output can allow much richer interaction with digitally mediated experiences. Second, and perhaps more importantly, building sensitivity towards human emotion and context into the ways systems process and present information can help push future products towards a paradigm that optimizes for deeper wellbeing rather than constant engagement. We need to learn from ourselves and apply the learning into the design of new computing paradigms. If we think of reality as the computing space, and our human experience as our perceived understanding of reality, our interface with this "reality" is our five senses and the conscious and sub-conscious ways we process the inputs we get from those five senses. Our sense of touch, sight, hearing, smell and taste dictates the signals we get from the world, and our perceptions and information processing abilities turn them into meaningful experiences. We output our commands through voice, gesture, expression, full body movements etc., and the feedback loop between when we physically manipulate objects and the reactive force we experience from our sense of touch seems instantaneous.

Humans don't necessarily perceive the environment in its true state; many magic tricks exploit the fact that human brains are constantly making predictions about what will happen next to give people the illusion of perceiving the world in real time, and while people think they see everything around them, the challenge of finding a set of keys left in a slightly odd spot suggests otherwise. People also experience perceptual narrowing when they are focused on a particular task, and tunnel vision when they are stressed. On the surface, this suggests that the human interface with the world is flawed, but it turns out that this ability to filter out most of what is actually happening confers many cognitive benefits. Donald Hoffman's work simulating two organisms with different types of perception evolving and competing for the same resources illustrates why this is the case. One of Hoffman's organisms perceived true reality, the other only saw well enough to maximize fitness for survival. In evolutionary simulations, the group that favored perception of reality went extinct much faster than the other group

[1]. Evolution favors fitness for survival and reproduction above all, and so devoting limited cognitive resources to more accurately perceiving the world if it provides no additional benefit is evolutionarily disadvantageous. Based on this finding, we could say that our perceptual narrowing quality is necessary in order to help devote as many cognitive resources as possible on the most important aspects of a given task.

Mihaly Csikszentmihalyi conceptualized the term "Flow" as the optimal experiences that are most enjoyable in human life while fully engaging in an activity. He investigated the close relationship between the state of Flow and enjoyment [2]. The state of Flow could be a manifestation of this evolutionary bias towards perceptual narrowing or focus on the task at hand to maximize the cognitive capacity available for completing it. We are much better at getting something done effectively when we are at one with the task; as a result, we're rewarded with positive emotional experiences when we are in the state of flow. When people enter the Flow state, they are fully immersed in the task at hand, lose any self-consciousness, become at one with their environment, and achieve effortless focus. The emotional byproduct of the state of flow is a sense of enjoyment, which leads people to be happier and more fulfilled.

Based on Csikszentmihalyi's research, people are able to enter the state of flow through achieving some expressions of the flow state. To begin incorporating richer humanistic qualities into the design of immersive digital experiences to encourage the Flow state, we might start by looking at the characteristics of being in Flow, and find ways to design for those characteristics by learning from how we perceive, process, and engage with reality.

1.2 Contribution

This thesis suggests ways of creating immersive digital experiences that encourage the state of Flow. It illustrates different methodologies and approaches for shifting people's mental states when engaging with immersive digital experiences such as virtual reality (VR) and augmented reality (AR) applications. It draws inspiration from disciplines such as user experience design, psychology, physiology, neuroscience and computer science, and it offers a cross disciplinary approach to the process of designing and implementing humanistic digital products and immersive interactions with virtual information. The design concepts introduced in the thesis act as examples of how designers and developers might encourage the state of Flow in immersive experiences, and they are shown at various stages of the product design and development process. Projects such as the Mind Controlled Fireworks app have been implemented and tested, while concepts like the Digital Steel Ball and the Priming for Productivity app are built without any tests. Other ideas such as the Emotive Brush and Responsive Notification System are at the concept design stage.

1.3 Thesis Organization

The thesis is motivated by the problems that exist in our interaction with computing devices currently, and the potential dangers of defining the interaction paradigm for immersive experiences such as AR and VR based on the direction of current mainstream approaches. Chapter one describes the need for a humanistic perspective to design and the advantages of enabling the state of Flow. Chapter two introduces the reasoning behind the approach, and gives more detail on the definition and identification of the Flow state. Chapter three explores underutilized humanistic qualities in current user experience design, and details the underlying mechanisms of those qualities. Chapter four outlines related work. Chapter five discusses approaches and example VR and AR application concepts that help people enter the state of Flow by shifting to an implemental state of mind, achieving a focused meditative sate, and engaging in creative expression. It also touches on ways to help people remain in Flow through conscious and subconscious interfaces. Chapter six discusses ways to promote more frequent and longer lasting Flow activities through encouraging a learning mindset and creating personalized and adaptive challenges. Chapter seven touches on application areas as well as the limitations of the approaches presented and potential hazards in their application. It then concludes the thesis and presents the references used.

Chapter 2

The State of Flow

2.1 Designing for Flow in the Context of Immersive Computing Environments

Since the sixties, Moore's Law predicting the exponential increase of affordable computing power has held, and this increase has allowed for a dramatic proliferation of digital experiences. We have seen computers first move into our homes, then into our pockets, and now AR and VR devices are merging our virtual experiences into our physical spaces. As VR and AR products gain traction among the general population, there is a unique opportunity to shape the interaction patterns that will influence the next generation of immersive computing experiences. Ideas like computer desktops and pull down to refresh are often treated as fundamentally intuitive today, but they were essentially just successful arbitrary design choices that could have been different at the time. However arbitrary these metaphors were, they are now so familiar that breaking away from them can be extremely difficult, even if objectively it might make very good sense to do so. More fundamentally, arbitrary decisions on underlying technology can leave us locked into undesirable paths as well. In 1900, the choice between internal combustion engines and electricity for powering cars was not clear cut, and both had advantages, but by 1950, the focus on internal combustion had lead to a transportation system and conception of the car that essentially prevented any meaningful attempt at electrification until very recently. This means that designing ideas like the promotion of psychological wellbeing into the foundations of new technologies like VR and AR can help shape people's conception of how these products can be used and will have a lasting impact on the developmental trajectory of human computer interaction in the years to come.

Many current consumer software product business models rely on the monetization potential of user data. End users often get services for free, but in exchange, their attention and engagement level are sold to advertisers. This incentive system depends on an increasingly scarce resource (people's attention), and the intense competition among companies operating under this business model is driving them to adopt more and more aggressive approaches to keeping people engaged with their products. A simple example is the red badge that appears on top of application icons when people get new messages. The design of the icon itself demands immediate attention and action, and companies looking to capture people's eyeballs constantly manipulate the type of message that triggers a new badge. When end users notice the appearance of a new red badge, they unconsciously experience an urge to open the app and respond. Facebook exploits this tendency and uses it to drive user traffic. They decided to trigger new badge notifications with messages and events that do not directly concern the user but might pique their interest. When other applications deploy the same scheme, end customers experience notification overload and their attention is pulled in all directions. Software companies using this technique can drive engagement up, but the impact on users' quality of life and productivity is increasingly negative. The self-defeating and destructive incentive structure will be amplified by the adoption of VR and AR products. Immersive displays replace users' personal space with computing spaces that are designed by software and hardware providers, the resulting experience of surrounding users with "red badges" screaming for attention from all directions is unthinkable. We must rethink the way we design and develop software products and platforms to allow for selective attention and enable people to focus on the task at hand. While app developers have no incentives to do this, platform providers to some extent do, as can be seen by Apple's increasingly aggressive global notification and privacy settings that apps have to abide by.

Mihaly Csikszentmihalyi highlighted the relationship between attention and wellness, and stressed the importance of being able to direct attention in order to reach the state of Flow. To control attention means to control experience, and therefore the quality of life. Information reaches consciousness only when we attend to it. Attention acts as a filter between outside events and our experience of them. How much we experience stress depends more on how well we control attention than on what happens to us [3]. Flow is associated with the feeling of enjoyment and positive affect, since a strong autotelic experience can even make external rewards appear redundant. Flow is experienced when deeply and actively involved in a task, performing at peak ability under high levels of concentration. The state of Flow allows people to reach the ultimate state of enjoyment. When someone enjoys doing something, he or she is more likely to live a happier and more fulfilling life. There is also a positive correlation between quality of performance and the Flow state. Being in Flow increases concentration, enjoyment, and self-esteem [3]. Csikszentmihalyi was motivated by the question "what contributes to a life worth living?" He wanted to find the roots of human happiness. His work is especially important today as we think about the relationship between technology and wellbeing. As designers and developers of the next computing platform, we have a compelling opportunity here to design digital experiences to enable the state of Flow.

2.2 What is the State of Flow

In Mihaly Csikszentmihalyi's book Beyond Boredom and Anxiety, he illustrates the fundamental pattern of how people find intrinsic motivation to pursue an activity. Flow is experienced when people perceive opportunities for action as being evenly matched by their capabilities. Flow activity provides optimal challenges in relation to the person's skill level, a person in the Flow state will perform action after action, and they do not think much about themselves in relation to their environment, between stimulus and response, or between past, present and future. They are able to be fully immersed in the task they are performing as if at one with their environment [2].

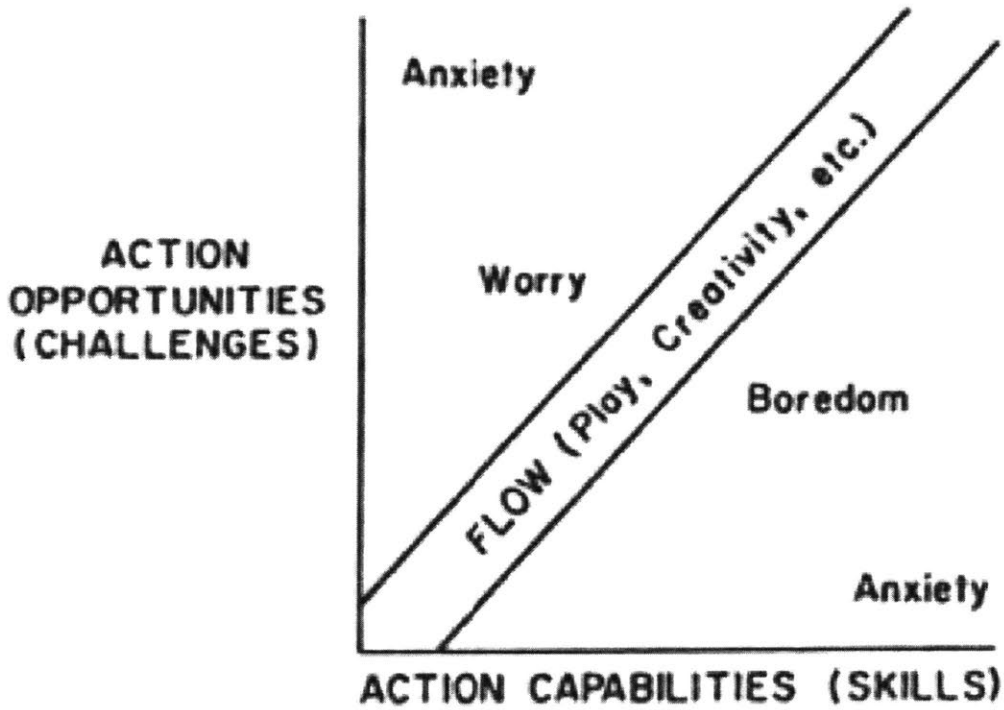


Figure 1. From Csikszentmihalyi's Beyond Boredom and Anxiety Book [2].

Csikszentmihalyi discovered that when people are completely absorbed in an activity, especially one that involves their creative abilities, they experience effortless concentration, a merge between action and awareness, unselfconsciousness, a feeling of being at one with their environment, and are left with a sense of genuine satisfaction [2]. For an activity to induce the Flow state, people need to have a clear goal and perceive a balance between the task difficulty and their ability to accomplish it, and they also need unambiguous feedback to continuously adjust their actions.

A person is able to enter the state of flow when there is clear feedback and an unambiguous goal. People are forced out of Flow when they encounter distraction, contradictory demands or actions that result in ambiguous feedback. When users are presented with a constant influx of notifications, they are always reminded of something else that they could be doing, which conflicts with the goal of their current tasks. This is an example of how current experience design fails at supporting the sate of Flow.

One of the main characteristics of people experiencing Flow is their autotelic personality. Autotelic is a word with the Greek roots auto and telos, which means self and goal respectively. An autotelic personality points to someone who engages in an activity for the sake of the process rather than the end result or external reward. A person in Flow experiences the task as intrinsically rewarding. The idea of leading a focused life and doing things for intrinsic rewards is not new. For example, this characteristic has parallels with a quote from the Bhagavad Gita where lord Krishna says "Let the motive be in the deed and not in the event. Be not one whose motive for action is the hope of reward." [3]

2.3 Measuring Flow

Csikszentmihalyi worked on identifying the different elements involved in the state of Flow through the Experience Sampling Method. He demonstrated its effectiveness in a study where teenagers were asked to record their activities and their relative state of happiness throughout the day. He found that those who were doing a task that required a high level of focus and energy reported to be happier. This test positively supported a key condition for Flow state to be possible, namely: subjects must perceive both the challenges in a given situation and their skill level to be high [2].

While the Experience Sampling Method is effective in identifying the Flow state subjectively, it also takes people out of the Flow state by introducing self-conscious evaluation. Researchers have recently begun to look for objective indicators of Flow that can be measured non-intrusively. In a study on the psychophysiology of Flow during piano playing, researchers looked at the relationship between subjective Flow reports and psychophysiological measures. They were able to find a significant relation between Flow and heart period, blood pressure, heart rate variability, activity of the zygomaticus major muscle, and respiratory depth. The researchers suggested that during physically and cognitively demanding tasks, an increased activation of the sympathetic branch of the autonomic nervous system in combination with deep breathing and activation of the zygomaticus major muscle might potentially be used as an indicator of effortless attention and the Flow state [4]. The results of this study demonstrate a step towards objectively measuring the state of Flow, although it does not provide enough evidence to establish clear boundary conditions between normal and Flow states. While the actual state of Flow is difficult to measure objectively, one of its component parts, focus, is something that can be measured through EEG sensors. This is useful, because high focus level not only indicates the possible presence of the Flow state, but it is also a necessary component of being in the Flow. This means that when designing interfaces that encourage a state of Flow, in addition to varying difficulty to match the user's ability, promoting focus is also a valuable component. Further, in a dynamic system, focus measurements can be used as a gauge of the interface's performance. This approach can be extended to other physiological signs such as breathing and heart rate, which can both be measured to gauge performance, and manipulated to encourage the user to enter a Flow state by setting up the necessary physiological and psychological context.

Chapter 3

Humanistic Qualities Underutilized in UX

3.1 Designing with underutilized humanistic qualities

Spatial information

On the human sensory side, we have the senses of touch, hearing, sight, taste and smell. Currently, computing interfaces primarily focus on sight and sound as outputs. We experience symbolic two-dimensional representations of information through a computer monitor or the surface of our mobile devices. The sense of touch we experience is largely limited to the same feedback force either from the mechanical push back of a key press or the rigid surface of a touch screen. Head mounted devices and other immersive displays open up greater possibilities to leverage our spatial processing abilities and full dexterity to interact with virtual information. This brings the ways people experience virtual information closer to how humans have evolved to process information from the rest of the world, and has been shown to improve performance in various tasks including memory and learning. For example, Ragan et al. showed that presenting information spatially improved performance in simple learning tasks representative of more complex activities [5].

Input: Continuous and simultaneous

For input, the current way of communicating intent to digital systems is through devices like keyboards, track pads, and mice. Fundamentally, people are pushing computers to do things by giving them one command at a time with deliberate conscious effort. Expanding the possible modes of input would allow continuous and simultaneous ways of expressing intent to computers. To do this, we need to think about input modalities that are both conscious and subconscious to the user so that interfaces can be made more immediate and brought closer to input and output modalities that humans have evolved to use in the physical world.

Tactile feedback makes touch interfaces much more usable. For example, artists have favored pressure sensitive styluses since long before multi-touch and force-press interactions became popular on mainstream consumer products because of the richer interactions they allow. AR and VR put us back into the 3D environment that we perform most of our tasks in, and it is a great medium to support both subliminal and conscious interaction decisions. EEG and other biometric data can allow computers to dynamically increase or reduce information based on cognitive workload while supporting continuous gestural inputs. Utilizing more subconscious cues can help interfaces become more like collaborators than tools, and help people take advantage of the rapidly increasing capabilities of information systems.

Processing: Decreasing mental workload by utilizing muscle memory and skill behavior

Mental workload is defined as the level of attentional resources required to meet the performance criteria for a particular task. We have many models to explain how we allocate attentional resources and make conscious decisions such as Rasmussen's levels of human information processing which illustrates three ways we make sense of our sensory inputs. We have skill-based behavior, rule-based behavior, and knowledge-based symbols [6]. Depending on the level of information processing, different levels of cognitive effort are required. The skill-based level can operate efficiently without our conscious attention, so we are able to go directly from feature formation to signal automated sensors-motor patterns. For the rule-based behavior level, we need to recognize signs and associate tasks based on rules that we stored in our memories. This relies on a cue-task association to recognize and process the information before applying the appropriate rule. At the knowledge-based level, we need to go through the decoding process of identifying the symbol, making a decision about the identified symbol based on our goal, and then plan around it before finding the rules for the task and execute on them. The closer to skill-based behavior, the less mental effort required of the user. The majority of our brain processing happens without our conscious knowledge. Utilizing that processing power directly frees up attentional resources and dramatically speeds up interactions.

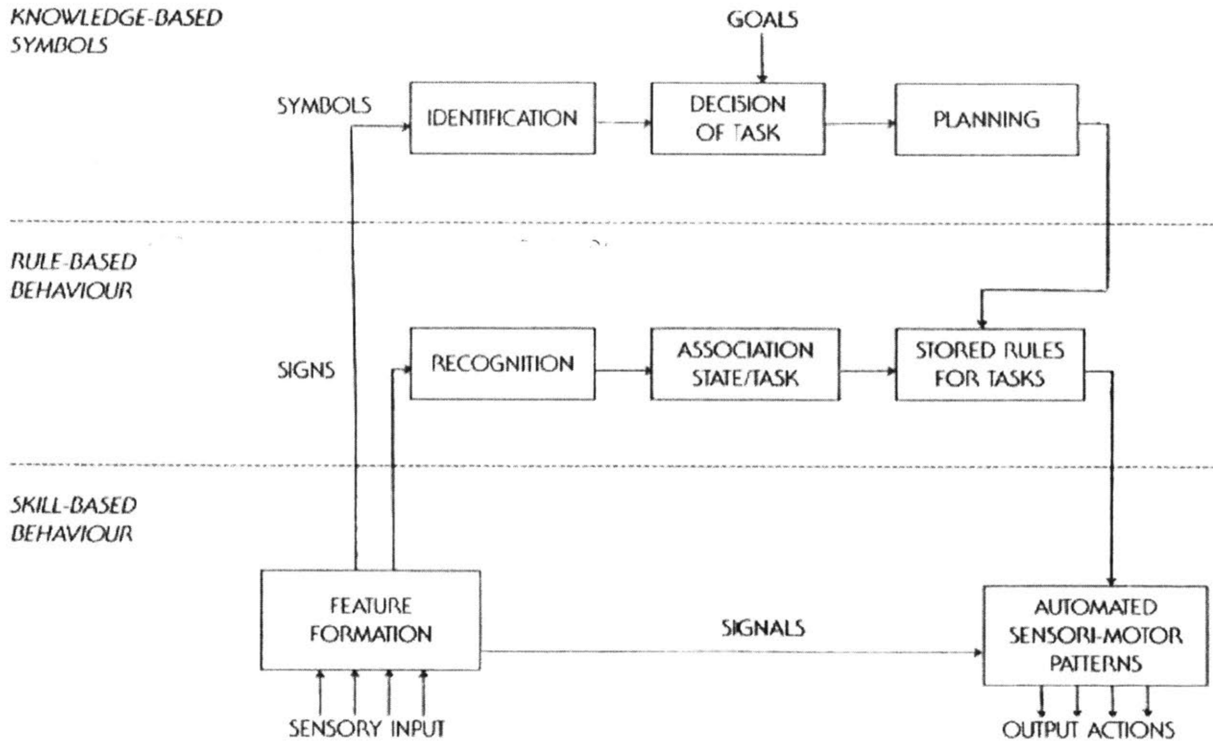


Figure 2. Rasmussen's Levels of Human Information Processing [6].

3.2 Conscious Processing

Neurofeedback and brain computer interfaces

Each of us has approximately 100 billion neurons, and each one fires at about 200 times a second and can connect to about 1000 other neurons. The speed and size of our processing power is incredible, yet our interaction with current computing devices is disappointingly slow. A study done by Karat, C.M et al. showed that typing speed for simple transcription averaged only 33 words per minute, and for composition the average was only 19 words per minute [7]. The dramatic difference between the speed of our information processing and our rate of interaction on a computing device presents an enormous opportunity for improvement.

For computer information output, immersive head mounted displays are becoming mainstream, and in the future continued miniaturization and improvements to display quality will accelerate this trend. Technologies such as transcranial magnetic stimulation where images are directly transmitted to the visual cortex open up even more possibilities [8]. These technologies support increasingly rich, hyper realistic experiences that have the potential to make virtual information nearly indistinguishable from the real world in terms of richness and sensory complexity.

As we develop better understanding of the brain, we will be able to improve our understanding of the human intent, as well as the emotional and cognitive state of the user. With this power, we might be able to support a human interface where users can output simultaneously and continuously into the computing space. We already have a few ways of decoding the electrical signals in our brains. The table below shows a summary of the state of our current brain detection technology.

Table 1.
Summary of acquisition method characteristics.

	Cortical surface	Intracortical	EEG	MEG	fMRI	fNIRS
Invasiveness and medical issues	Invasive	Invasive	Non-invasive	Non-invasive	Non-invasive	Non-invasive
Spatial resolution	High	Very high	Low	Mediate	High	Mediate
Temporal resolution	High	High	Mediate	Mediate	Low	Low
Portability	Portable	Portable	Portable	Non-portable	Non-portable	Portable
Recorded signal	Electrical	Electrical	Electrical	Magnetic	Metabolic	Metabolic

Table options

Figure 3. Brain computer interfacing: Applications and Challenges [9].

Among the technologies shown in the table above, EEG presents the most promise for this thesis. It is non-invasive, portable, and there are a number of relatively inexpensive commercially available devices. EEG data captures the brainwave frequencies naturally occurring in people's brains. All frequencies are present at the same time, but there is usually one dominant band depending on current mental state and activity. Delta waves are the slowest, usually between 1 and 4 Hz, and are associated with deep sleep. Theta waves are slightly faster at 4 to 8 Hz, and usually connected to creativity, memory, meditation and daydreaming. They are also associated with the hypnogogic state in-between wakefulness and sleep. Slow Delta and Theta waves are also linked to subcortical brain regions involved in affective processes [10]. Alpha waves are even faster, usually between 8 and 12 Hz. This band is associated with creativity and goal setting. It's also highly correlated to visual processing [11]. Beta waves can be anywhere between 12 and 32 Hz, and are associated with intense focus and cognitive control processes [12]. Gamma waves are between 38 and 42 Hz, and are associated with short-term memory matching of recognized objects [13]. This frequency has been quite extensively studied for insightful problem solving [14]. It is worth nothing however, that neuroscientists still debate on the exact boundaries between these frequency bands [15].

Neurofeedback is a method used for self-regulating neurophysiological signals. It is an active way of altering a particular state of mind. In contrast, brain entrainment temporarily shifts a person's mental state by boosting one frequency over others. It is a passive way to force the brain into a particular state. Monaural, binaural and isochronic beats in combination with visual stimulus have been found to be the most effective method for delivering brain entrainment. Many researchers have demonstrated the effectiveness of both techniques in therapeutic and self-improvement use cases. The brain physiological self-regulation conducted by Sterman et al. in 1974 described the application of EEG Neurofeedback (NFB) for the therapy of patients with epilepsy [16]. While neurophysiological self-regulation training often shows high reliability and impressive results, the learning effects are still poor. Also, not every signal component is suitable for self-regulation; components such as the slow waves, the amount of alpha and sensorimotor rhythms are highly individualized. This presents an opportunity to apply personalized machine learning algorithms to adapt signal recognition to each user.

3.3 Subliminal Interfaces

Dijksterhuis [17] suggests that unconscious processing is much more powerful than conscious processing. Dijksterhuis showed that subliminal conditioning could enhance a person's self-esteem [18]. Positive subliminal cues showed significant improvement in learner's inductive reasoning, causing subjects to have a dramatic increase in performance and intuition in logic based problem-solving tasks [19].

Tactile sensory inputs such as temperature and texture detections can also have a dramatic impact on people's perceptions. People perceive others as warmer and more generous when holding a warm drink, and become more selfish when holding a cold drink. Similarly, people perceive themselves and others as tough negotiators when sitting in a rigid hard surfaced chair, and soften when sitting in a plush sofa [20].

Other studies have shown the influence of context on the response to sounds. When people hear a sound (a "sound object" or a "sound event") the perceived auditory space around them might modulate their emotional responses to it. Small rooms are considered more pleasant, calmer, and safer than big rooms, although this effect of size seems to disappear when listening to threatening sound sources. Sounds heard behind listeners tend to be more arousing and elicit larger physiological changes than sources in front of listeners. These effects were more pronounced for natural, compared to artificial, sound sources, as confirmed by subjective and physiological measures [21].

Chapter 4

Related Work

A number of people have explored the relationship between the state of Flow and productivity or wellbeing, as well as the impact of physical context on people's emotions and memory. This thesis draws on this research, particularly the work of Mihaly Csikszentmihalyi in defining and characterizing the state of Flow. The thesis seeks to extend this work by suggesting more ways in which immersive user interfaces can encourage Flow, potentially leading to better productivity and improved overall wellbeing.

4.1 Flow

Experiencing the flow: design issues in human-robot interaction

In their project, Patrizia Marti, Leonardo Giusti, Alessandro Pollini and Alessia Rullo investigated the possibility of using robotic devices to engage humans in activities that would likely result in the Flow state. They were able to prove a positive correlation between playing with the Paro robotic seal and the Flow experience through the perception of time among experiment participants. They also investigated methods to help people achieve the Flow state where action and awareness merge when users interacted with I-Blocks. They suggested that to improve control, the functionality should be completely transparent to the user at first glance, and that a concurrent feedback condition encouraged the state of flow more than systems that gave users a final feedback. Finally, they showed that the ability to build a physical construction of the robot and to define a consistent software program is crucial for the success of LEGO Mindstorm robots. When people understood ways to create coherent conceptual models of the whole system, and when they were able to meaningfully integrate the physical and digital dimension, they were able to enter the state of Flow [22].

"Not another Z piece!" Adaptive Difficulty in TETRIS

Katharina Spiel, Sven Bertel, and Fares Kayali investigated the link between perceived difficulty and fun in Tetris games, and tested a novel way of unobtrusively varying difficulty. By measuring performance in real time and adjusting difficulty by selecting more or less usable game pieces, they suggest that the game can be dynamically adjusted without confusing people already familiar with its behavior [23]. This approach is particularly interesting because without finding ways of accommodating legacy interaction models and applications, it will be more difficult to drive widespread adoption of flow promoting interfaces.

Find Your Flow: Increasing Flow Experience by Designing "Human" Embedded Systems

Chen-Ling Chou, Anca M. Miron, and Radu Marculescu argue it is increasingly necessary for experiences to be designed to promote the Flow state, and suggest a three part framework for promoting Flow; analyzing task difficulty and user ability, characterizing system resources, and system optimization. They show that users are most likely to enter Flow when they are able to utilize several applications on a system (a possible proxy for skill) at high CPU utilization (a proxy for effort/engagement) [24]. This suggests that while task switching can be detrimental to flow, tool switching isn't always, and offers some interesting ways of inferring whether or not users are in the flow state. The proxies for effort and engagement used are also applicable to a wide range of general application.

Maintaining Concentration to Achieve Task Completion

Ben Shneiderman and Benjamin Bederson suggest three strategies for promoting concentration in productivity tools. First reduce the amount of information people must keep in working memory by flattening navigation and surfacing relevant information (even at the expense of creating a slightly dense interface). Second, increase information richness to take advantage of people's pattern recognition abilities. Third, increase automaticity by including shortcuts and other ways for experienced users to work faster than they can think [25]. These basic principles can provide a useful framework for starting to design interfaces to promote flow, although the precise implementation details must be considered on a case-by-case basis and can make or break both the interface's ability to promote flow as well as its overall experience.

The Experience of Flow in Computer-Mediated and in Face-to-Face Groups

Ghani et al show that computer mediated group collaboration sessions are more conducive to flow than in-person sessions. They suggest this might be because of the more controlled setting, which allowed for better focus, and the higher degree of challenge associated with the task when working through a computer [26]. The effects they show, including the ability to completely control the user's environment to help them focus provide support for concepts such as using immersive (and therefore more mediated) experiences to help users focus and enter the flow state.

Measuring flow in gamification: Dispositional Flow Scale-2

Hamari and Koivisto demonstrate a 36-item scale for measuring the flow state based on aspects of Csikszentmihalyi's original nine dimensions of flow. They highlight the idea that of Csikszentmihalyi's dimensions, some are conditions for Flow, and some are the result of entering the Flow state. Preconditions for flow include creating challenge-skill balance, clear goals, control, and feedback. Once people are in the state of Flow, we could look for loss of self-consciousness, changes in time perception, concentration, and merging action-awareness as the indicators of the Flow state. Interestingly, unlike other work, their analysis suggests that at least in certain types of gamification, creating an autotelic experience is a precondition and not a marker of flow [27].

4.2 Embodied Computing

MemTable

In their project, Seth Hunter, Pattie Maes, Stacey Scott, and Henry Kaufman explored how contextual triggers can be used to aid memory recall during group collaboration settings. Hunter et al showed that providing contextual, multi-modal capture during group collaboration settings slightly improved overall recall, and greatly improved the level of detail people could describe after the event [28].

Remembrance Agent

Bradley Rhodes investigated methods to utilize context, continuous background environmental sensing and occasional proactive prompting to allow computer systems to augment human memory. Remembrance Agent is a wearable just-in-time information system that continually reminds the wearer of potentially relevant information based on the wearer's current physical and virtual context. Traditional file storage systems can only be accessed through keyword search which forces the user to recall the name of the file, or browsing which forces the user to scan a list and recognize the name of the file. Those methods are easy to program but require the user to do the brunt of the memory task. Human memory does not operate in a vacuum of query-response pairs. The context of a remembered episode provides lots of cues for recall later, and so bringing computer systems closer to human perception and memory can allow them to provide more effective support in cognitive tasks [29].

4.3 Affective Computing

Brightbeat

Asma Ghandeharioun and Rosalind Picard showed that modulating light, temperature, and sound can reduce heart rate and breathing, leading to a calming effect. Their behavior change intervention does not require constant attention, and had minimal impact on the other activities people engaged in. The intervention worked by influencing breathing pattern passively through a series of visual, tactile and auditory signals [30].

PsychicVR

In her project, Judith Amores used brain computer interface in a virtual reality environment to increase mindfulness. The system used real time brain activity measured from the MUSE headband to control 3D objects in an Oculus Rift VR environment that encouraged the user to focus. The system offered a playful way of improving focus and concentration [31].

Using Frustration in the Design of Adaptive Videogames

Kiel M. Gilleade and Alan Dix outlined the two types of frustration common in video games; “in game” such as with a difficult puzzle, and “at game” such as when a console crashes. Their research concerns whether existing hardware can be used to detect and measure frustration during play. They outlined several challenges including the fact that many physiological markers of frustration are simply indicators of arousal, which is common for other emotional states during game play [32].

"I'm happy if you are happy." A model for emotional contagion in game characters

Dimas et al documented a model for simulating emotional contagion in video game characters. They showed that their model improves the likability of non-player controlled characters, and suggest that their model could improve player experience. Although their work focused on computer controlled game characters, its ability to simulate mirroring could have interesting applications in situations where a system can measure a user's affective state [33].

MoodWings: A Wearable Biofeedback Device for Real Time Stress Intervention

MacLean et al prototyped and tested a device for measuring users' stress levels and providing them a conscious way to reduce anxiety. Interestingly, their test subjects actually experienced a higher level of stress than the control group, although they performed safer driving habits than the control group and expressed positive attitudes towards the device [34].

Biofeedback Game Design: Using Direct and Indirect Physiological Control

to Enhance Game Interaction

Most research projects on physiological input for games have been focused on dynamic adaption of game environmental factors such as difficulty level; Nacke et al proposed a system for direct physiological control. Their study showed that players preferred consciously controllable physiological inputs such as breathing to unconscious attributes such as heart rate. Subjects also commented that the added dimensions of control made an otherwise quite simple game much more immersive [35].

The main focus of this thesis is to promote the state of Flow through unobtrusive methods such as those suggested by Shneiderman and Bederson [25] or shown by Spiel et al [23]. Integrating these ideas into applications also requires finding ways of measure Flow, either through direct methods such as EEG signals, task outcomes, or through implicit proxies such as those suggested by Chou et al [24]. Because the Flow state is not directly measurable, but can have an impact on people's overall emotion and wellbeing, work in areas such as affective computing is also relevant. Finally, the impact of embodied computing is often substantial in the outcome of immersive experiences. Projects like MemTable [26] demonstrate the importance of environmental and social context on people's ability to recall information.

Chapter 5

Getting to Flow

5.1 Approach

Csikszentmihalyi has described how some people can start a Flow episode just by directing their awareness to conform to the requirements of Flow, like limiting the stimulus field so as to allow the merging of action and awareness. This suggests that incorporating the necessary conditions for Flow to occur when designing immersive experiences could have a big impact on encouraging users to experience the Flow state. In other words, helping people achieve some requirement of Flow could help them start a Flow episode. This thesis focuses on helping people achieve Flow by encouraging concentration, meditation training, promoting an implemental state of mind, and lowing the barrier to engage in creative endeavors. The next chapter also looks at ways of prolonging the Flow state through subliminal interfaces and reducing potential distractions.

5.2 Enable the Implemental Mindset

When people decide to take on a task, their perception of how well they are able to execute on the chosen goal is highly dependent on their current frame of mind. A deliberative mindset pushes people to underestimate their ability to accomplish a task and therefore encourages inaction. Conversely, an implemental mindset primes people to look for immediate actions to take on and leads to an optimistic assessment of the likelihood of achieving the goal [36]. Put another way, the deliberative mindset creates cognitive bias towards information relevant to making goal decisions based on feasibility and desirability. The implemental mindset biases a person's cognition to implementation related information [37]. An implemental mindset is characterized by a concentrated focus on the essential elements of immediate execution. People are concerned with the issues of how, when and where goal-directed actions are to be initiated, maintained and completed. Some research studies suggested that the mere act of making a decision which passes an individual from a pre-decisional state to a post decisional state leads to increases in intrinsic motivation and enhanced performance [38].

These studies suggest that by enabling the implemental mindset, people's perception of their ability to accomplish a task and their chances of success can be increased, which will get them closer to the state of Flow. For example, instead of presenting users with a menu of choices when they enter a virtual or augmented environment, leveraging the system's understanding of the user and contextual information could allow inferences such as the user's intentions or preferences which can be used to reduce or eliminate choices for the user to make. Based on the system's understanding of users' intentions, it could give them spatially presented visual information that they are able to take immediate actions on. Filtering out unnecessary choices helps prevent users from second guessing their intentions, and primes them to think about concrete steps toward accomplishing their goals, thus nudging them towards an implemental mindset.

Design Concept 1 - Workspace Spatial Memory

Instead of asking people where they want to go, drop them in the context as if they've already made up their minds.

Use case: As someone producing work inside of an augmented reality workspace, I want to quickly enter the zone and not have to think about recreating my digital space every time I begin my work.

Solution: Use object recognition based 3D workspace and leverage people's superior spatial memory to quickly get them back into a particular state of mind while working within an immersive digital workspace.

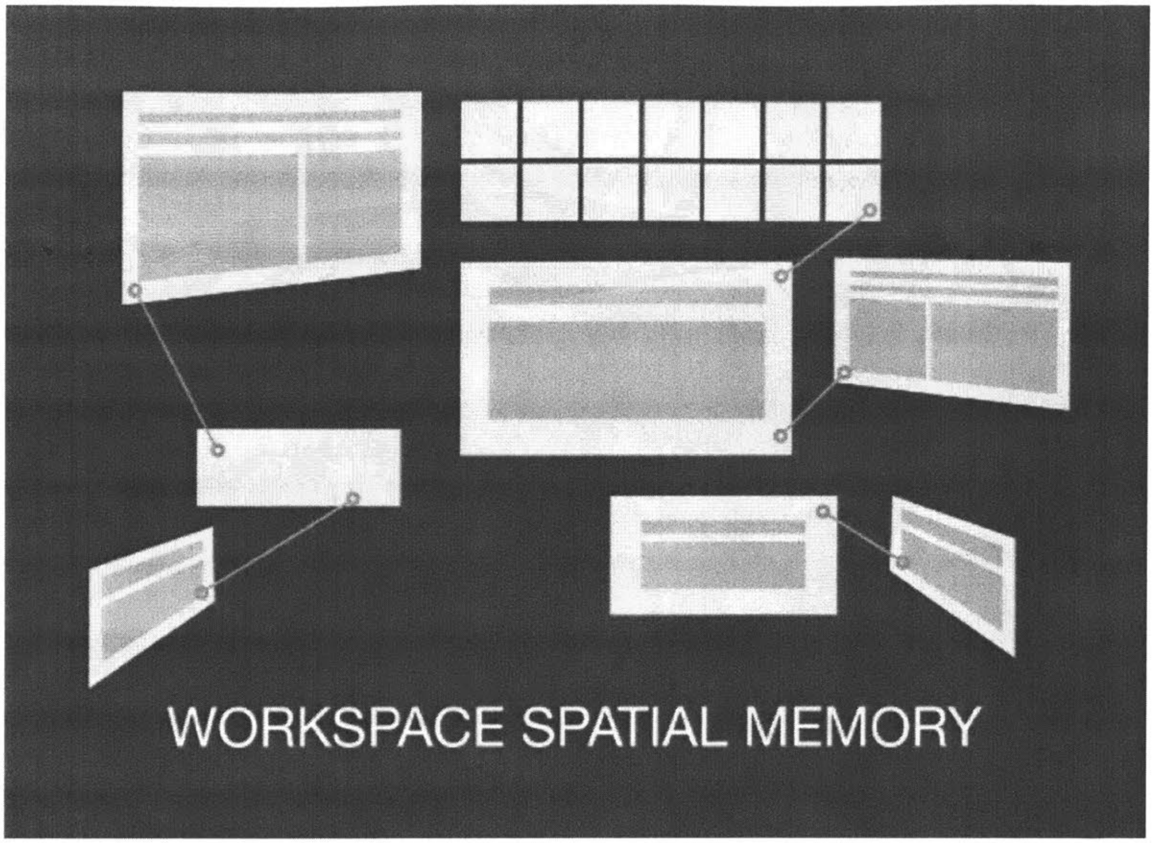
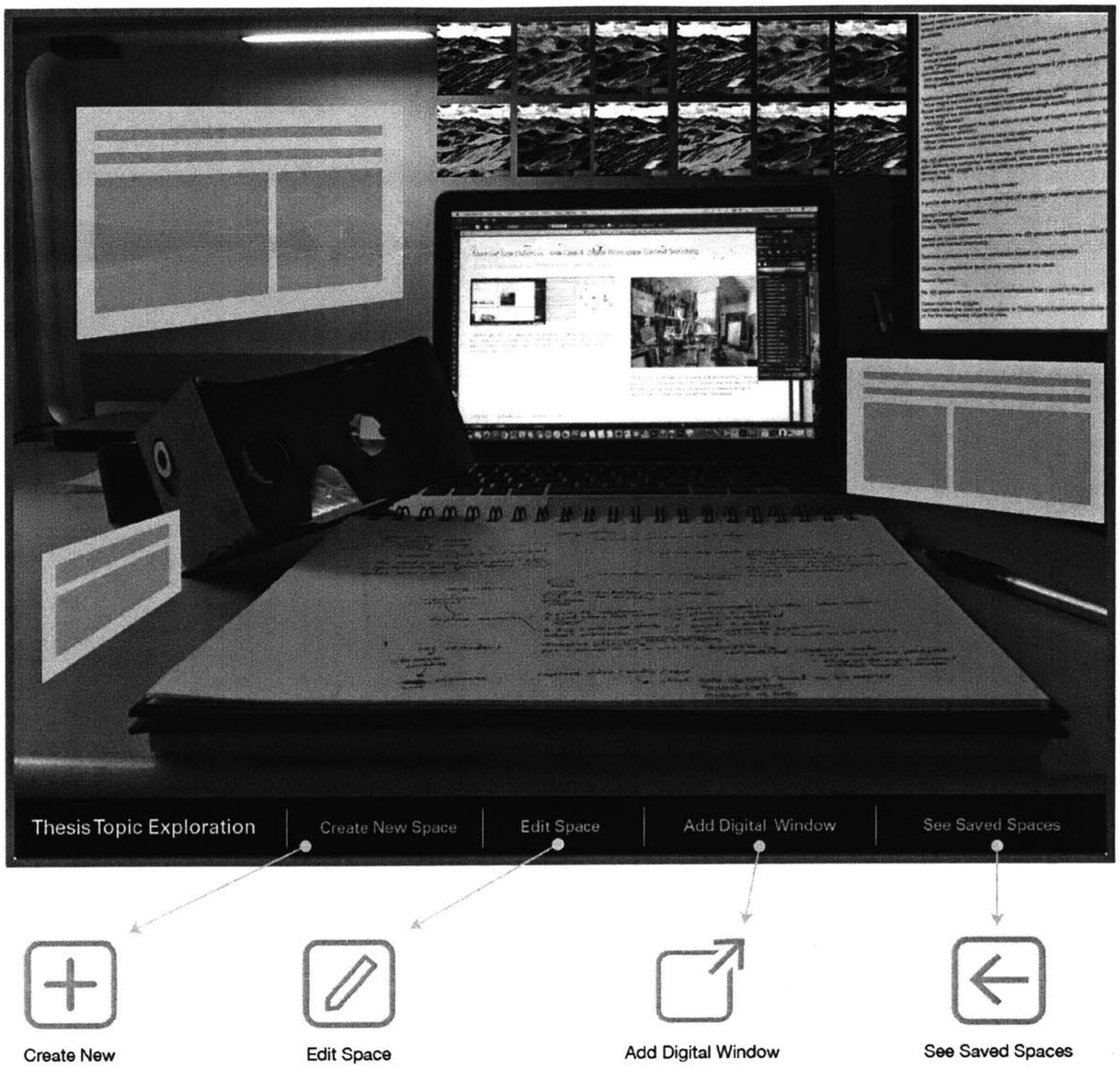


Figure 4. Workspace Spatial Memory – Overview.

Every time someone switches tasks, they are prone to distractions from emails, and social network messages, etc. as they are closing and opening the relevant software programs. Setting up a workspace and getting into the right mindset requires a lot of cognitive effort, so what if people could just sit down and have all the relevant workspace information appear in front of them? Similar to how artists are able to quickly get back into a creative mindset by walking into their studios, we could leverage our spatial memory to retrieve the right mental model and emotional state necessary for entering a productive state of mind.

Storyboard 1 Accessing Workspace

1. Based on recognized objects in the scene, the user's augmented reality glasses display the most relevant workspace the user has saved in the past. All digital content saved from the previous session appear around the physical objects on her desk, just as she left them last time. This helps her get right back to the task she was doing, and encourages an implemental mindset.



Save a new version of the current space.

Save over the current version. Users are able to edit the digital content shown in the scene, edit links between digital and physical information.

Users are able to bring a new digital window hosting any of their desktop apps.

See a list of other saved spaces.

Figure 5. Workspace Spatial Memory – Accessing Workspace.

Example scenario: The user's augmented reality glasses detect that the user is at her desk. The system also detects her computer and notebook, which implies that she is working on a project. Based on the available contextual information, the system displays the most likely workspace for her to work in.

2. After the user activates the edit space functionality, she can manipulate the links between physical and virtual information. The user has the option to link a new digital window to a physical object, or just have the digital window float in space.

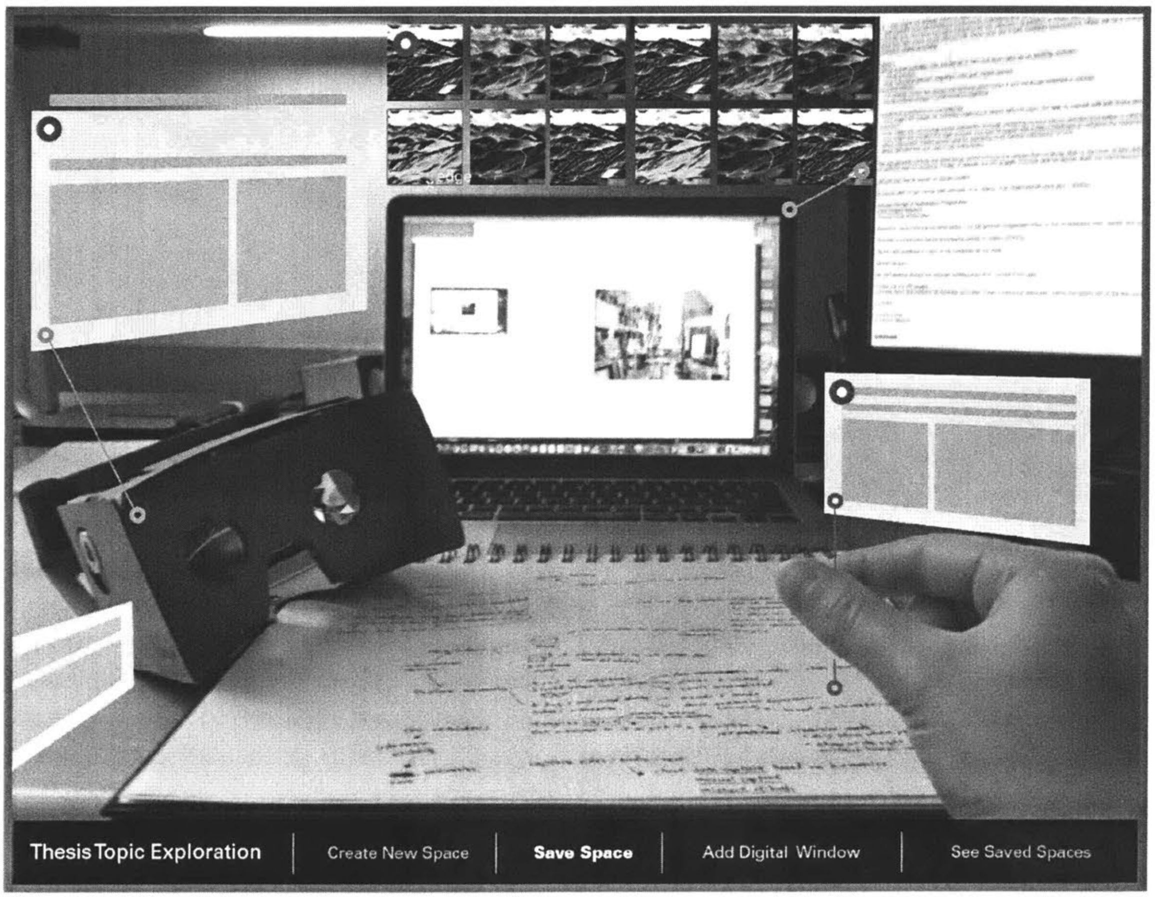


Figure 6. Workspace Spatial Memory – Edit Space.

3. The user can see other saved spaces by activating the See Saved Spaces button.

Figure 7. Workspace Spatial Memory – See Saved Spaces.

Storyboard 2 Sharing the Workspace

1. The user can share a virtual version of the physical object, and she can also chose which digital window to include in the shared virtual object.

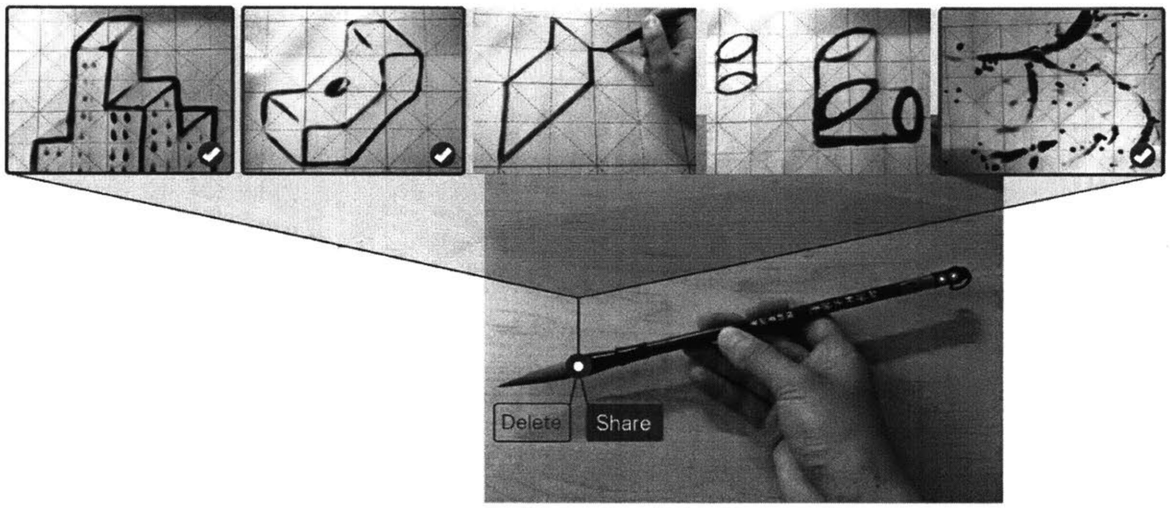


Figure 7. Workspace Spatial Memory – Share Virtual Version of Physical Object.

2. The recipient of the virtual object could attach it to a physical object in her space.

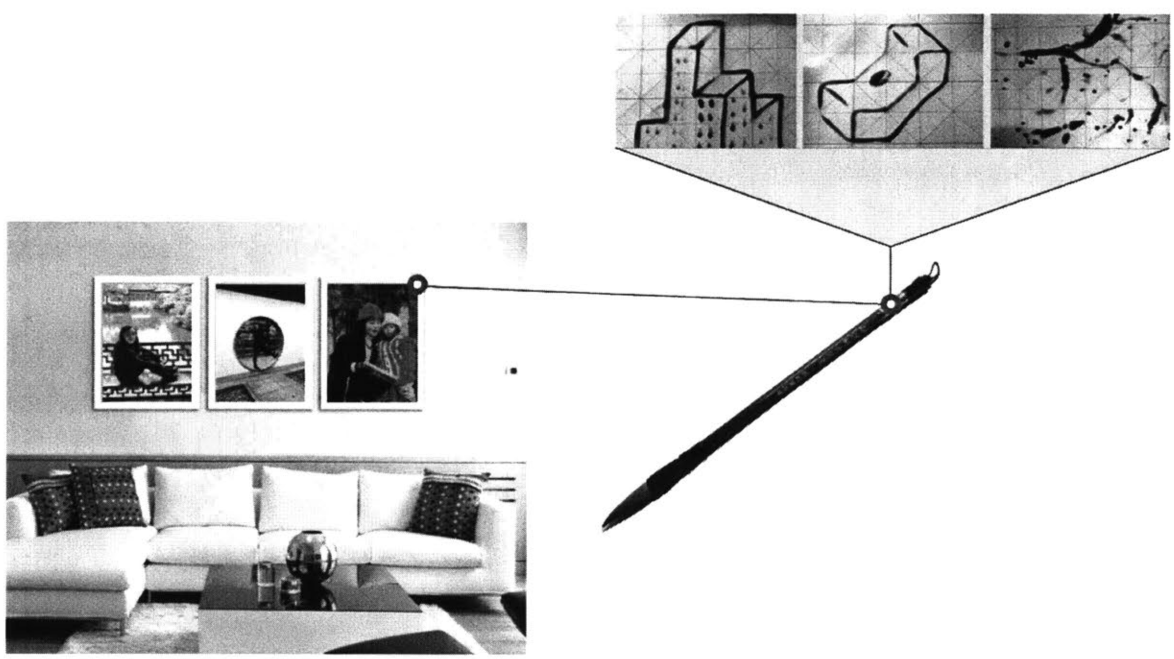


Figure 8. Workspace Spatial Memory – Organize Shared Virtual Object.

Design Concept 2 – Priming for Productivity

Quickly get back into an implemental mindset by watching an animation of the workspace when previously productively engaged in a task.

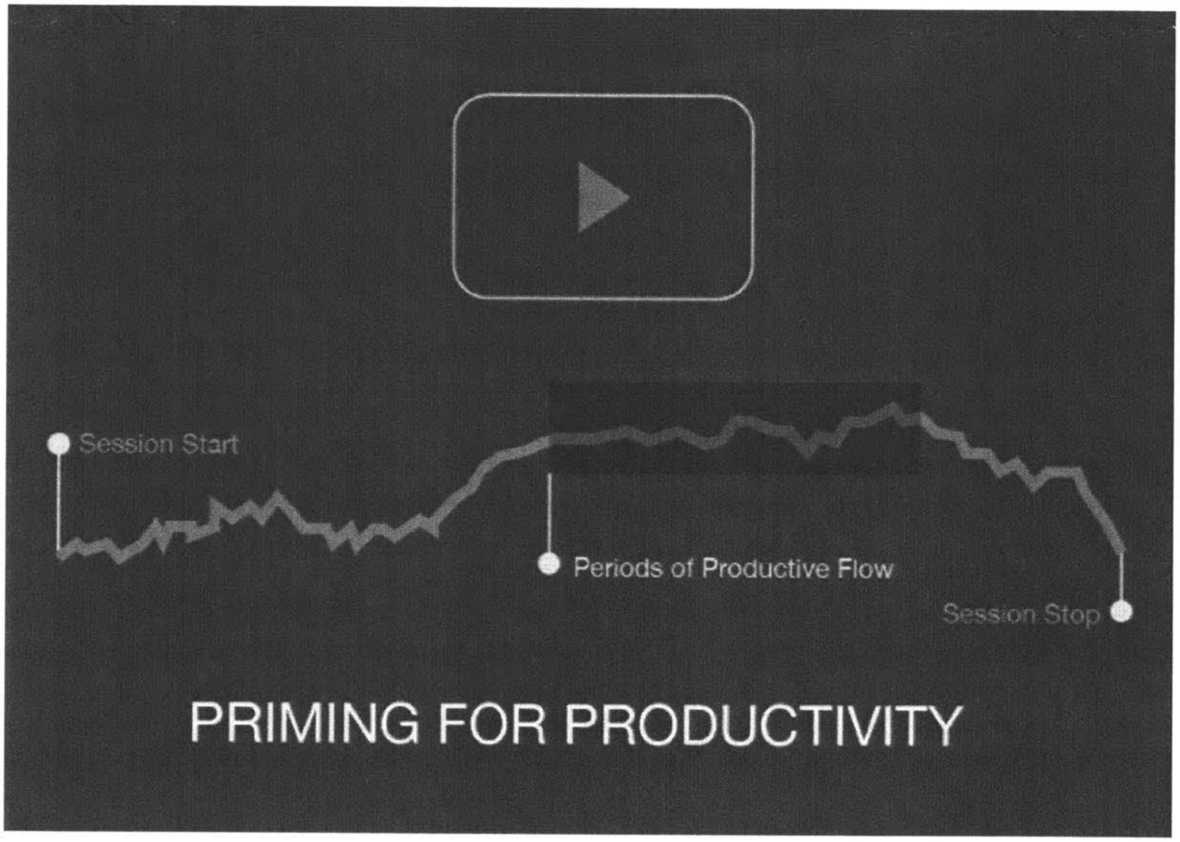
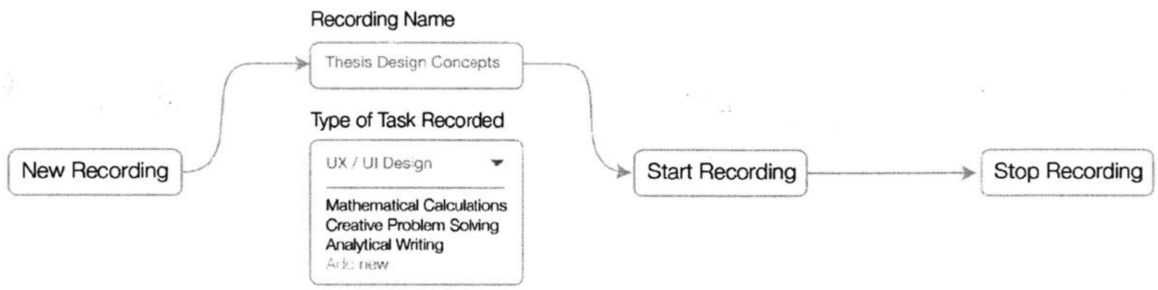


Figure 9. Priming for Productivity – Overview.

In addition to navigational choices that support an implemental state of mind, users can be primed to get back into a state of Flow for an existing task. There is a certain amount of short-term memory involved when people engage in a particular task, especially for those who solve problems from multiple perspectives. Switching frameworks of thinking can take a significant amount of mental effort, the retrieval or rebuilding of the short-term memory developed when working through a particular problem can cause a large latency between when people decide to work on a task and when they are able to become fully productive. Similar to how some writers read what they wrote during the last productive session before continuing on with their new work, many people might benefit from a reminder when they return to their tasks after an interruption. The priming for productivity tool aims to facilitate the retrieval of the memories required to continue performing well for a given task by showing users key moments from their last engagements. Through an animated replay of how their workspaces evolved under high concentration, the system brings people back to their prior state of productive flow through memory association, and equips them with the short term memories they developed last time to pick up where they left off.

User Action: Record Work Session



1. Puts on EEG tracker and clicks on the new recording button in the positive priming app.

2. Selects the type of task being recorded, and gives it a name.

3. Clicks on the start button to initiate the recording.

4. Performs the task, clicks on stop after completion.

System Actions

1. Establishes connection with EEG headset via bluetooth and prepares a new folder for the recording.

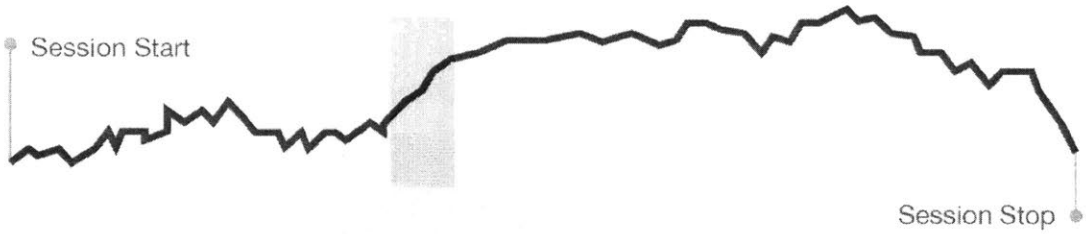
2. Creates a new folder under the UX/UI Design folder.

3. Begins to take one screenshot every second and stores screenshots in the UX/UI Design folder.

4. Stops taking screenshots.

Figure 10. Priming for Productivity – User Journey and System Actions.

Sample concentration level in one session



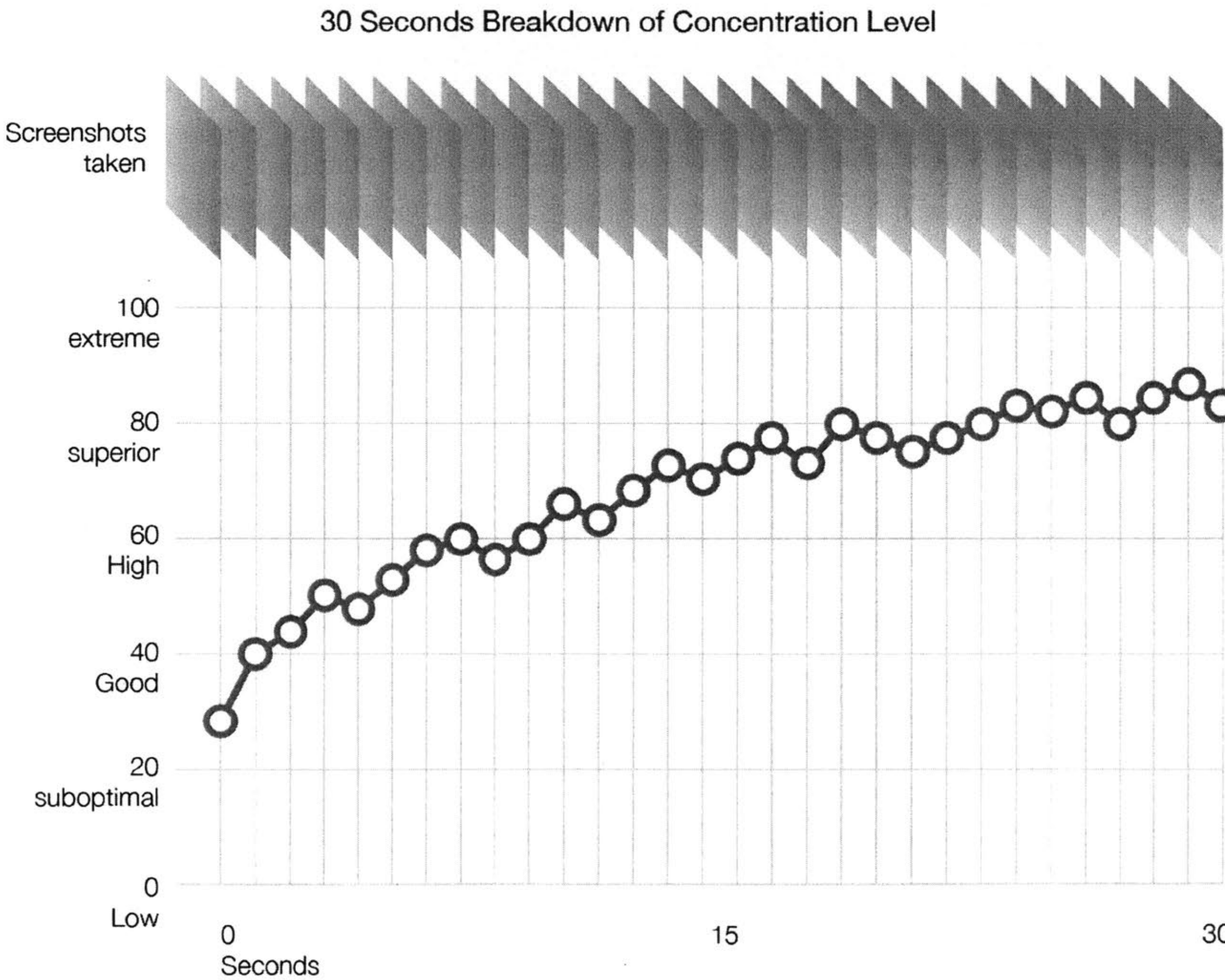
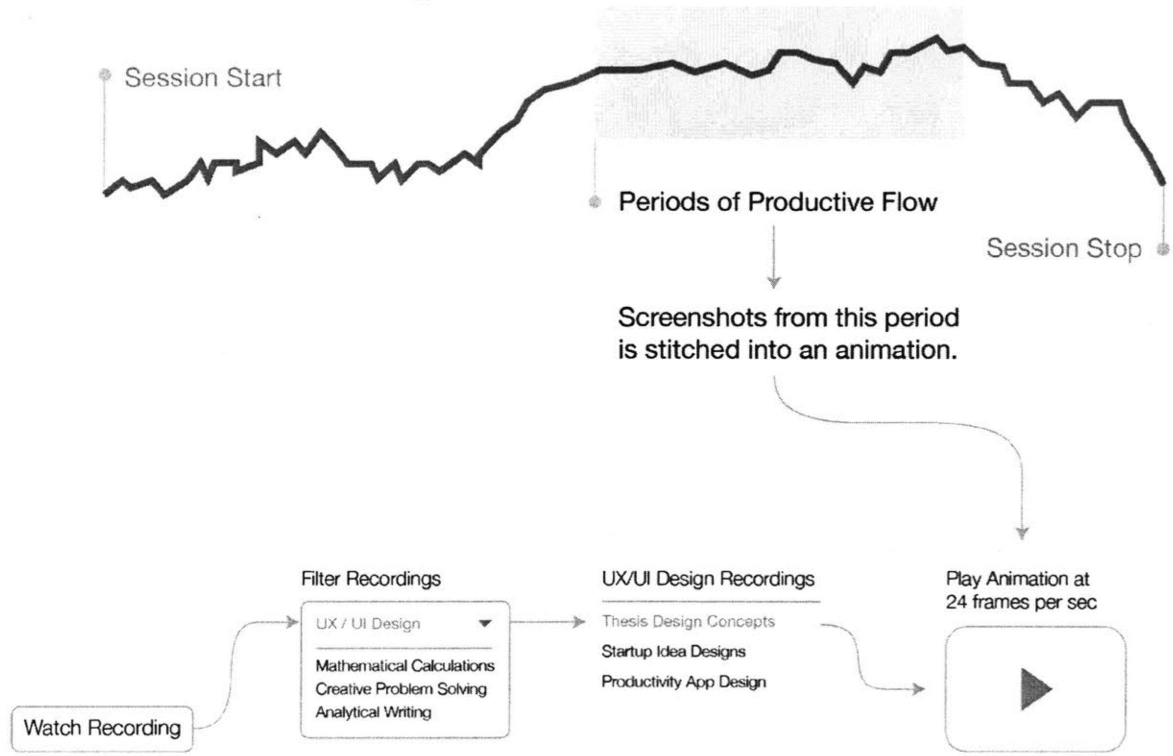


Figure 11. Priming for Productivity – Data Collection.

User Action: View Recordings



1. Opens the productivity app and clicks on the Watch Recording button.
2. Choses the recording category.
3. Selects the recording title.
4. Watch the animation.

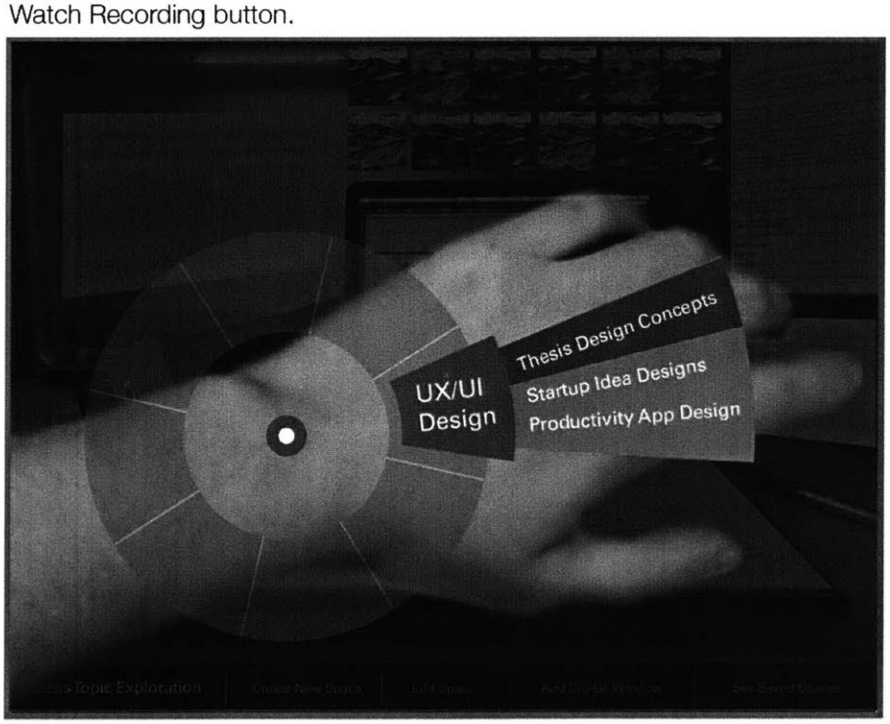


Figure 12. Priming for Productivity – Recording Playback UX.

5.3 Flow and Concentration

A distinct characteristic of being in the Flow is effortless focus. “When you’re in the flow, concentration is like breathing - you never think of it. The roof could fall in and, if it missed you, you would be unaware of it.” [2] This description illustrates the effect of our selective attention when we are in the state of Flow. Attention is increased awareness directed at a particular event or action to give it the greatest possible processing power. Normally, people have so called divided attention where they rapidly switch focus between across multiple areas. Those who experience Flow are able to take control over the direction of their attention, and keep it in one area long enough to enter a sustained state of focus.

In order to help people achieve a state of Flow, application designers and developers could encourage users to learn how to actively direct their attention. In a virtual reality or augmented reality environment, every component within the user’s field of view can be edited and controlled, which allows the detectability of objects to be adjusted based on user’s state of focus. For example, if we want users to focus on a particular object, we could increase its resolution and contrast while slightly reducing those qualities on less important objects. We could also design the system to respect the prioritization of the user’s attentional resources. Instead of treating all object renderings at the same level, each object in the environment could be assigned a prioritization number or attentional cost, which could allow the system to limit the total attention required at any given time.

Objects could also be rendered in accordance to the user's focus, reducing distractions even further when they are deeply engaged. This can be made possible by eye tracking technologies coupled with foveated rendering.

Another way to help people focus is to provide them tools to learn how to control the direction and duration of their attention. Neurofeedback has been shown to be effective in treating children with ADHD [39]. Kaiser did an extensive study with 1,098 patients with moderate deficits, and demonstrated the effectiveness of neurofeedback training in improving attentiveness and impulse control [40]. By externalizing people's attentional level, we are closing the loop between a person's concentration effort and the feedback he or she receives. This closed loop approach allows people to try a variety of methods to gain conscious control over their attentional spotlight.

Design Concept 1 - Set Off Fireworks With Your Mind

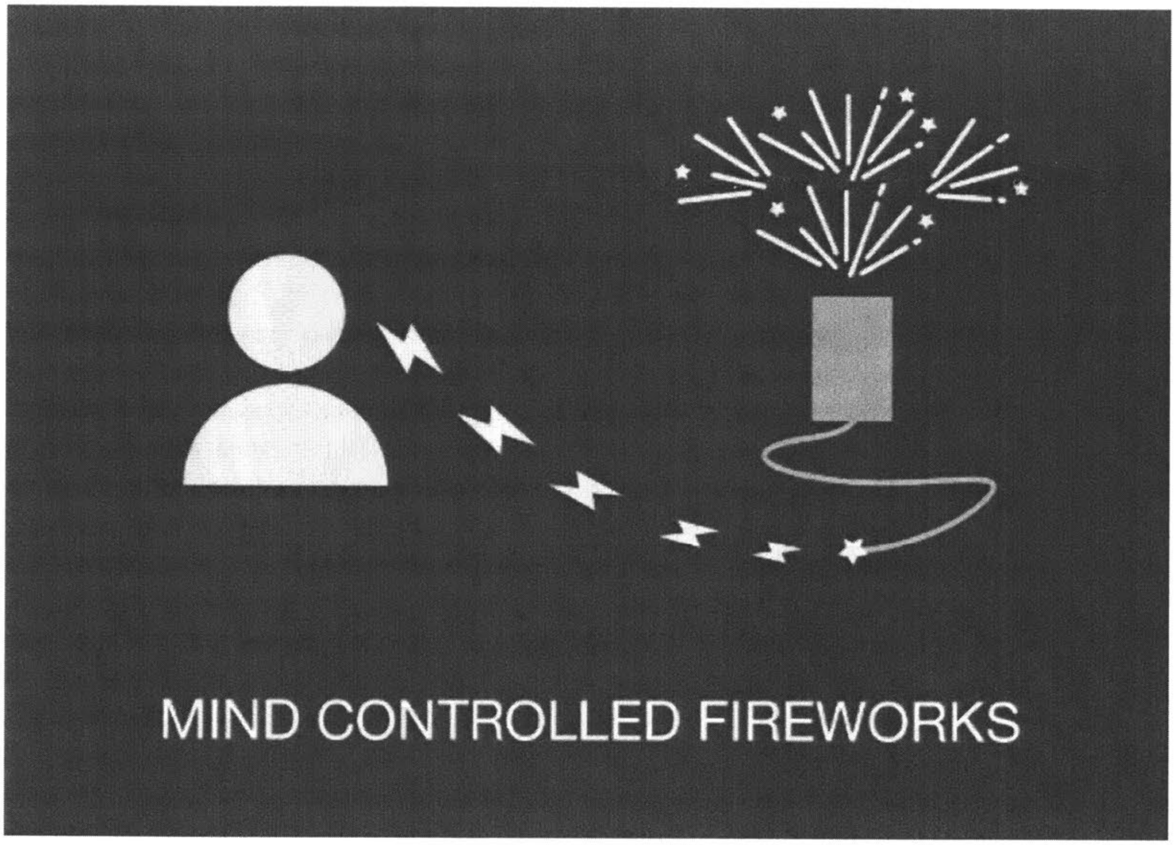


Figure 13. Mind Controlled Fireworks – Overview.

Improve concentration control and duration through a biofeedback VR game that provides people with incentives to train their ability to control their concentration. People can propel a spark along a fuse leading to some fireworks with sustained attention detected through an EEG sensor.

Game Mechanism

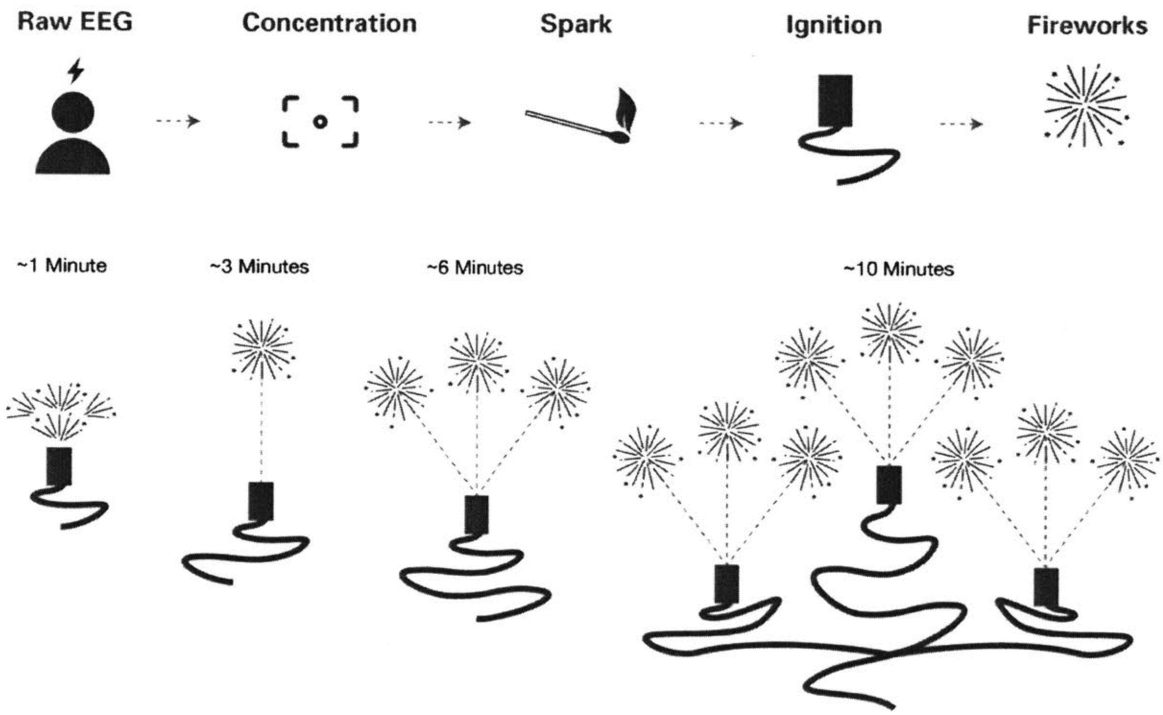


Figure 14. Mind Controlled Fireworks – Game Mechanism

Storyboard

1.Select the level of difficulty.

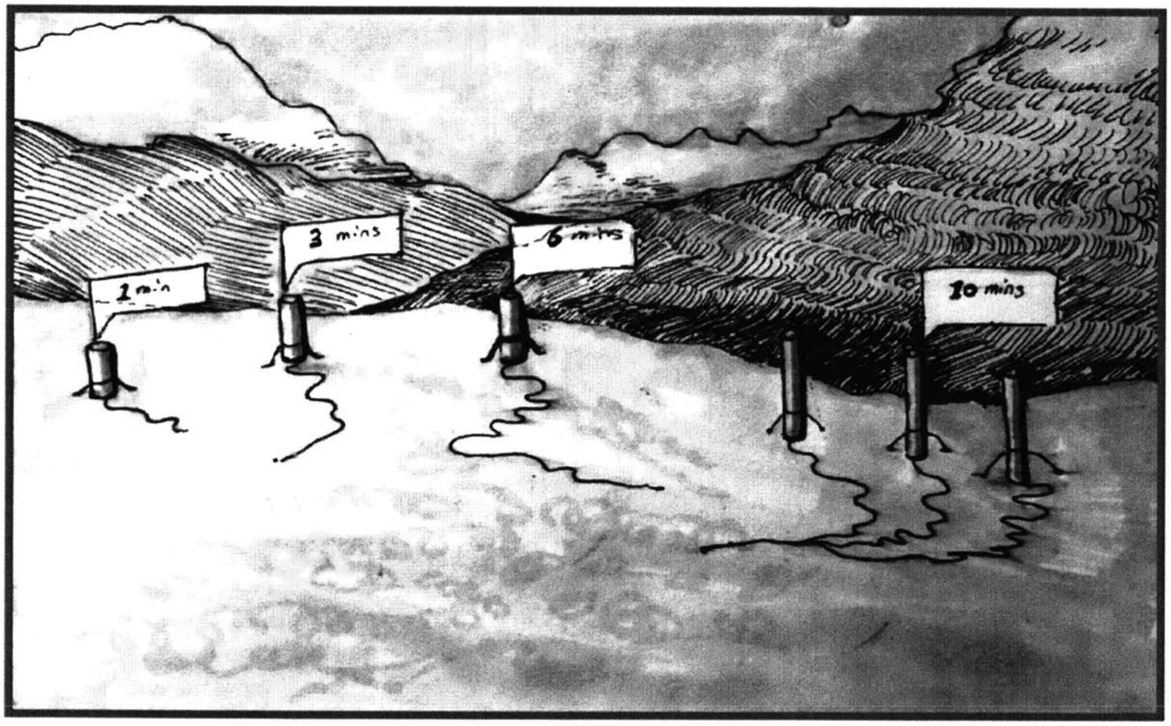


Figure 15. Mind Controlled Fireworks – Select difficulty.

2. Increase concentration to move the spark closer to the firework base.

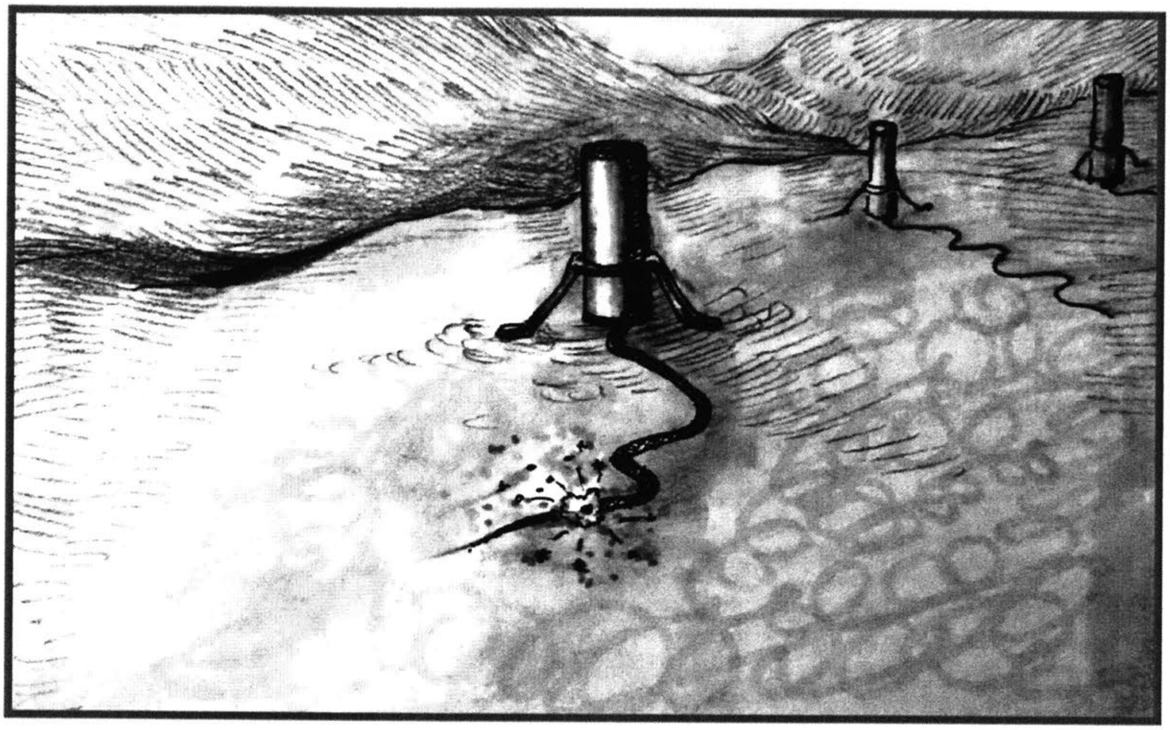


Figure 16. Mind Controlled Fireworks – Increase Concentration.

3. Enjoy the fireworks!

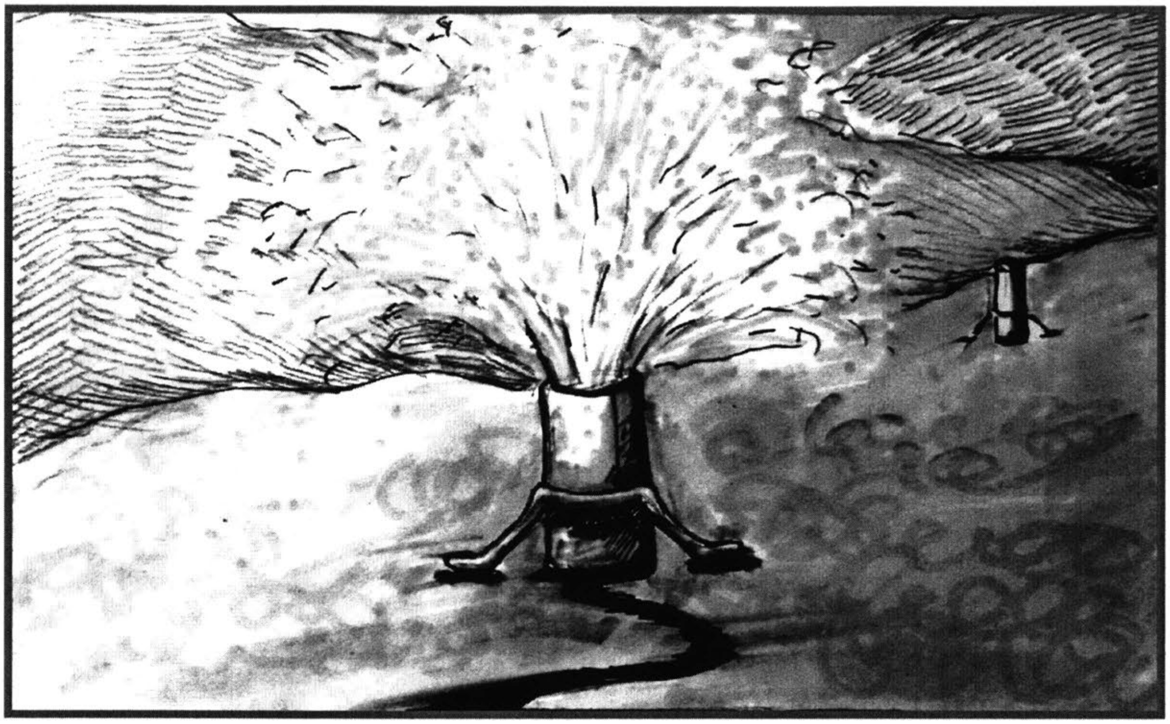


Figure 17. Mind Controlled Fireworks – Enjoy the Reward.

VR Prototype Screenshots

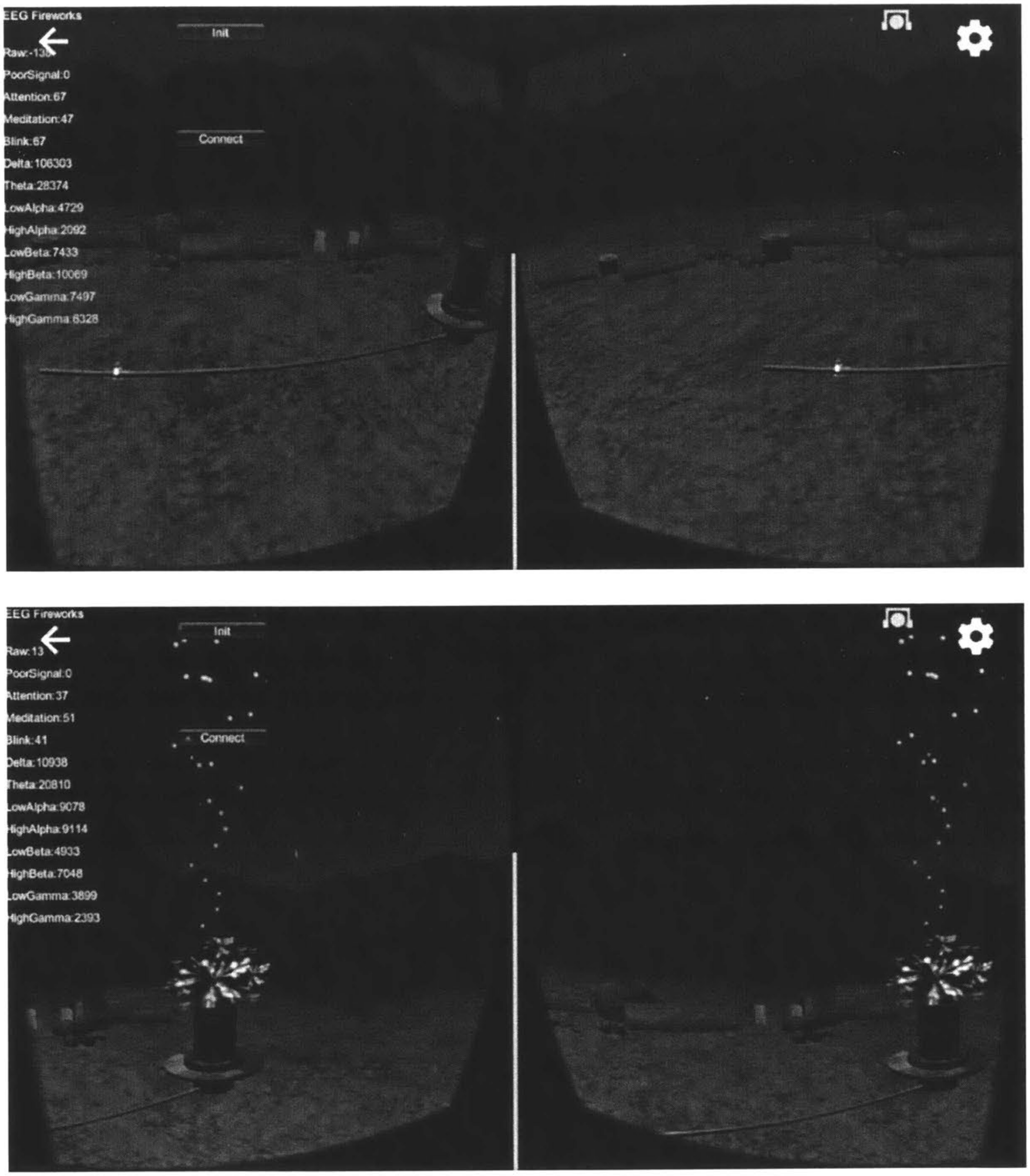


Figure 18. Mind Controlled Fireworks – Prototype Screenshots.

Software: Unity, MonoDevelop, xcode,

Hardware: Neurosky Mindwave EEG sensor

User Study

Goal

The mind controlled fireworks VR game aims to help people learn how to control their level of attention. The main goal of this user study is to determine if people can learn to enter a concentrated state of mind with the VR neurofeedback game, and sustain their focus in a subsequent concentration task.

Independent Variables

1. Exposure to the mind controlled fireworks VR game.
2. Exposure to a VR game environment.

Dependent Variable

Concentration task performance.

Potential Confounding Variables

Subjects' familiarity level with virtual reality varied from very comfortable to only having had one prior experience in virtual reality. The novelty of the experience may have some influence on the study results.

Experiment Procedure

Subjects were fitted with a Neurosky Mindwave EEG sensor and received three treatments in a randomly selected order: control, VR environment exposure, and

VR neurofeedback fireworks game. Following each treatment, they performed a timed online concentration task. Every subject received all three treatments. The goal of the concentration task is to uncover all of the blocks by finding a pair of the same image in sequence. Here's a look at the beginning and the end state of the concentration task:

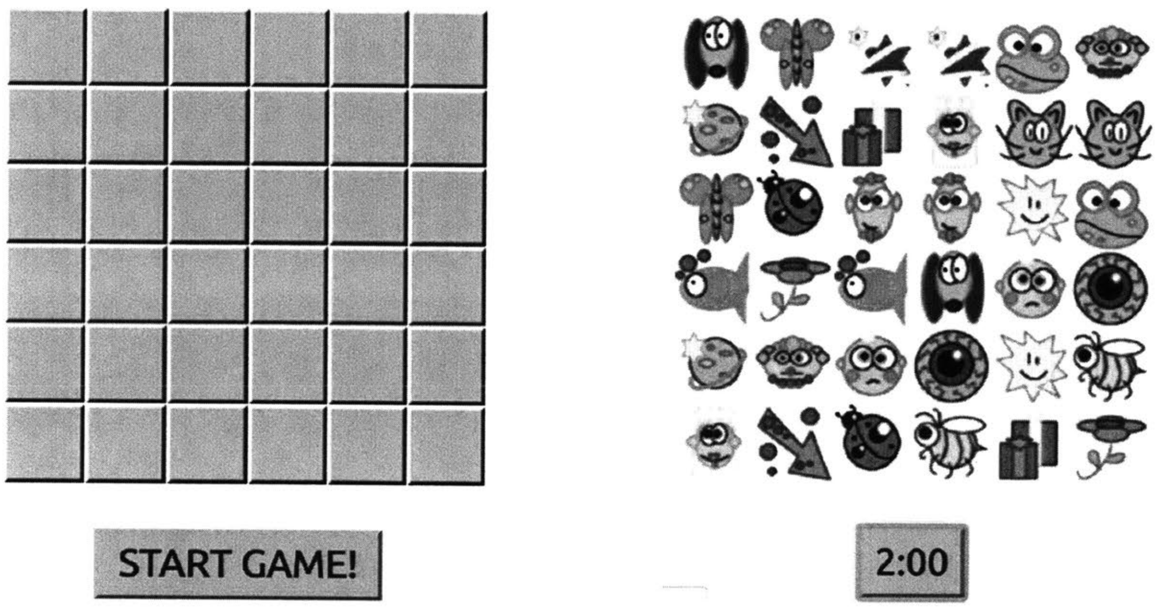


Figure 19. Mind Controlled Fireworks – Online concentration task used for testing users' concentration ability. Users must uncover matching pairs of images in sequence.

Randomized Treatment Presentation Options:

Each user completed all three of the following tasks in random order.

1. Control. Users were asked to take a two minutes break and then perform the online concentration task.

2. VR Environment. Users were asked to put on the VR device and explore the Mind Controlled Fireworks game environment without the neurofeedback game mechanism. They were asked to look around for two minutes. Users were then asked to perform the online concentration task.

3. Neurofeedback Game. Users were asked to put on the VR device and push the spark in the game environment towards the base of the firework by increasing their focus level. After successfully lighting the fireworks, they were asked to perform the online concentration task.

For example, a user might be asked to put on the VR device and use their focus level to activate the fireworks (the Neurofeedback Game), then complete the concentration task. Next they might be asked to take a two minute break (the Control task) before completing the online concentration task a second time. Finally, they might be asked to put the VR device on and explore the fireworks game environment for two minutes (the VR Environment task) before completing the concentration task a third time.

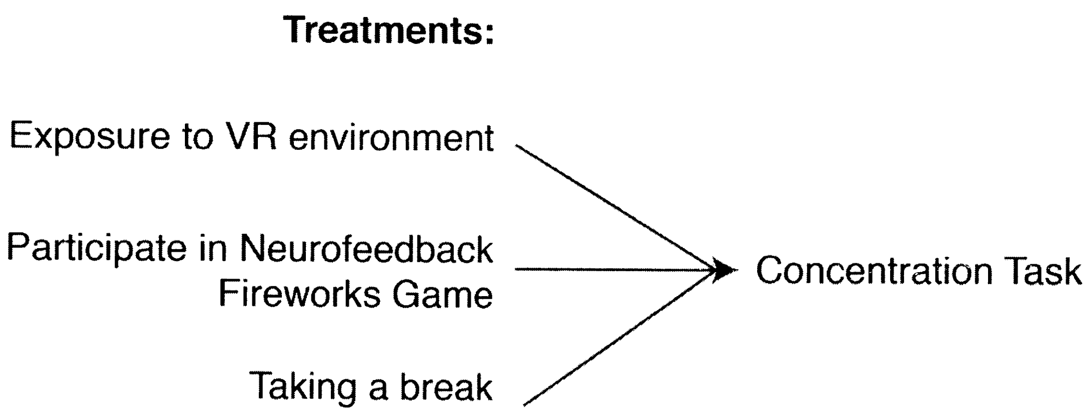


Figure 20 Experiment Treatments.

At the end of the study, participants were asked to describe their experiences and provide any feedback they might have.

Subject Recruitment

Seven male and four female graduate students between the age of 21 and 30 were recruited.

Time to complete online concentration task after being exposed to each treatment

Subjects	Control (secs)	VR environment (secs)	neurofeedback game (secs)
Subject 1	135	107	91
Subject 2	128	121	123
Subject 3	107	163	111
Subject 4	176	150	190
Subject 5	135	126	171
Subject 6	123	94	119
Subject 7	119	102	100
Subject 8	95	130	102
Subject 9	137	156	114
Subject 10	152	172	84
Subject 11	131	132	123
Subject 12	147	160	120
Average	132.083333	134.4166667	120.6666667
Standard Deviation	20.1347889	24.67271885	29.57006745

Figure 21. Experiment Results.

Data Analysis

We performed statistical analysis between the control and the neurofeedback game treatment, the control and the VR environment treatment, as well as the VR environment and neurofeedback game treatment. Our null hypothesis for this study was that there was no different between each treatment pairs. In this experiment, we have three dependent sets of data since each participant received three treatments. Because we have less than thirty participants, we will use a two-sampled t-test with dependent samples as our statistical method. The equation used to find the test value was:

$$t = \frac{\overline{D} - \mu_D}{s_D/\sqrt{n}}$$

Where D is the difference between two sets of data being compared, this allows us to analyze individual performance variability between each treatment conditions. We have 12 participants (n) in total, so our degree of freedom (d.f) is n-1=11.

Control and the Neurofeedback Game Treatment

The alternative hypothesis was that there was a statistically significant increase in performance for the neurofeedback game treatment. We will use the one-tailed analysis. Using a t-distribution table, we find that at a 99% (a = 0.005) confidence interval, our one tailed critical value is 3.106. The mean difference between the performance of the control and the neurofeedback game treatment is 11.417. The difference in standard deviation is 9.435. Based on the t-test dependent sample equation listed above, our test value is calculated to be 4.19. Comparing our calculated test value to our critical value, we see that our test value falls within the critical area t = 4.19 > 3.106. Thus, we successfully rejected the null hypothesis. We conclude that there is a significant increase in concentration task performance after exposure to the neurofeedback game in comparison to the control treatment.

Control and the VR environment treatment

The alternative hypothesis was that there was a statistically significant difference in performance between the control and the VR environment. We will use the two-tailed analysis to find if there is a difference. Using a t-distribution table, we find that at a 99% (a= 0.01) confidence interval, our two-tailed critical value (c.v) is 3.106. The mean difference between the performance of the control and the VR environment treatment is 2.333. The difference in standard deviation is 4.538. Based on the t-test dependent sample equation listed above, our test value is calculated to be 1.78. In comparison to our critical value 3.106, we see that our test value does not fall within the critical area $t = 1.78 < 3.106$. Thus, we fail to reject the null hypothesis. We conclude that there is no significant difference between the performance of control and VR environment treatment.

VR environment and neurofeedback game treatment

The alternative hypothesis was that there was a statistically significant increase in performance for the neurofeedback game treatment in comparison to the VR environment treatment. We will use the one-tailed analysis with a confidence interval of 99% (a =0.005, c.v = 3.106). The mean difference between the performance of the VR environment and the neurofeedback game treatment is 13.75. The difference in standard deviation is 4.897. Based on the t-test dependent sample equation listed above, our test value is calculated to be 9.73. Comparing our calculated test value to our critical value, we see that our test value falls within the critical area $t = 9.73 > 3.106$. Thus, we successfully rejected the null hypothesis. We conclude that there is a significant increase in concentration task performance after exposure to the neurofeedback game in comparison to the VR environment treatment.

Comments from participants

" I applied the same feeling as I got from the VR game when doing the concentration task, and I was able to increase my performance, but as soon as I started to observe this learning, my performance decreased…"

This comment indicated the potential of successfully transferring the learning from the VR game to another concentration-based task. It also illustrated Csikszentmihalyi's description of how people break out of flow when becoming self-conscious.

Design Concept 2: Concentration Based Tetris Game

Increase or decrease the visibility of the game objects in real time based on user's concentration level.

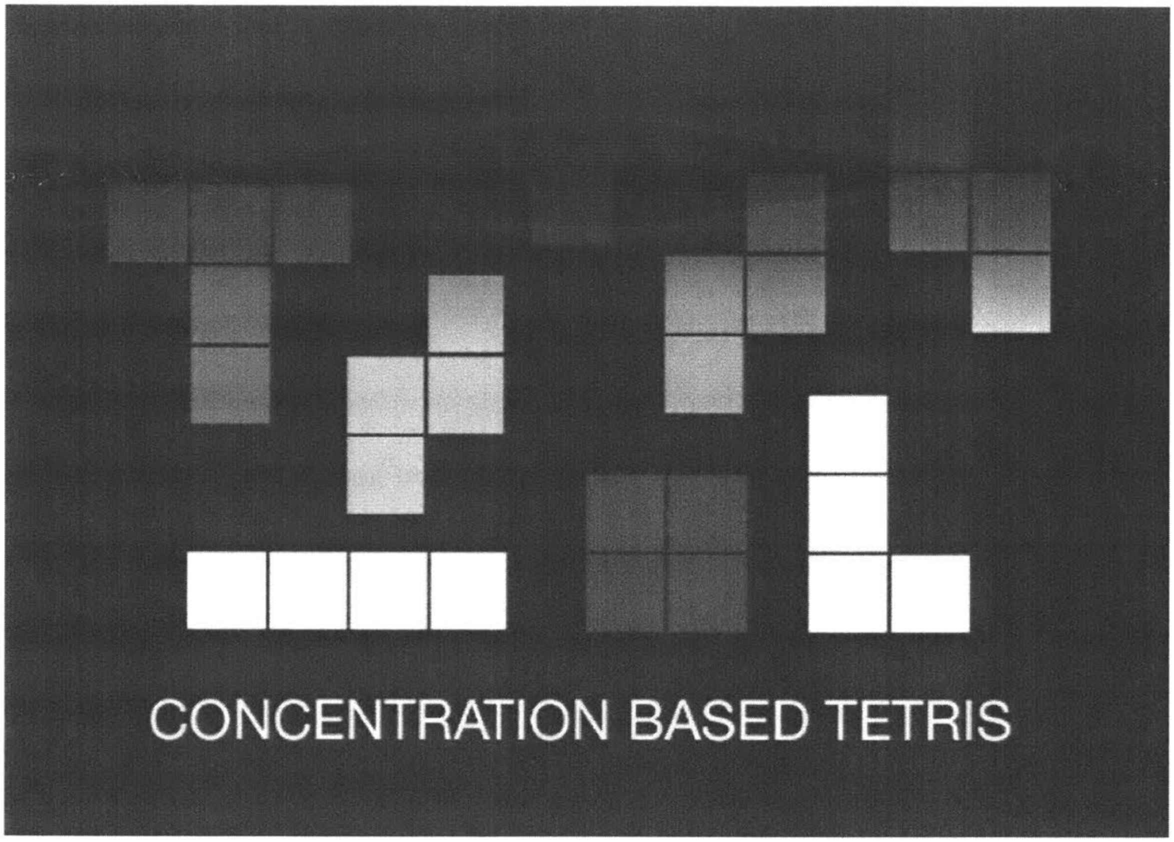


Figure 22. Concentration Based Tetris – Overview.

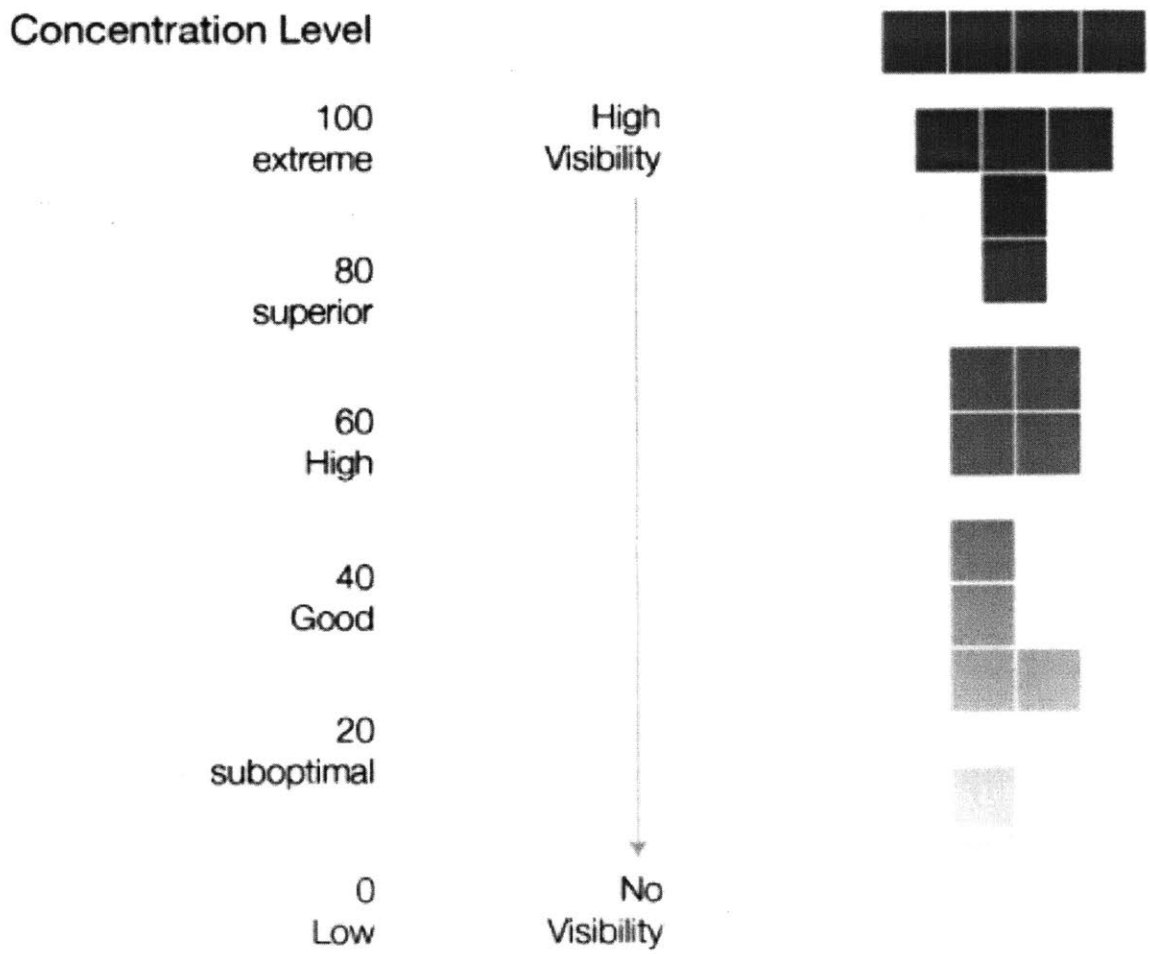


Figure 23. Concentration Based Tetris – Game Mechanism.

Daniel Oppenheimer did a research study where he gave two groups of students the same information but printed in different fonts. The group that got prints with more difficult to read font actually retained the information better. His study proved the effectiveness of the disfluency intervention in improving memory performance [41]. The difficult to read fonts were unconventional, which took participants out of their comfort zone, they had to pay more attention to overcome that slight discomfort, and that extra attention allowed them to process the information better. Of course, as people become more accustomed to the font, the disfluency effect disappears. What if we introduce a responsive disfluency factor that adapts to each person's attention level? We could provide users who want to increase their productivity a tool that changes the visibility of their workspace based on their concentration level. When their minds are wondering and their productivity levels low, the objects on the screen will decrease in opacity. This can cause them to subconsciously refocus as shown in Oppenheimer's work [41]. Instead of wasting time in front of their workspace, they can either play a concentration game to help them get back into a focused state of mind or take a break and come back with a fresh mind.

The same mechanism could be applied to the concentration based Tetris game; the game mechanic acts as a change of pace to users' regular workspaces. The goal of the game is to help people learn to control the opacity of the objects on screen using their concentration level, eventually; people could increase the visibility of their workspace without having to play the Tetris game.

The attention levels detected from EEG sensors control the opacity of the game objects. The game objects will become translucent if users lose focus. The game allows users to simultaneously control the orientation of the game pieces as well as the opacity level. Users are incentivized to train their mind to have a higher concentration level so they can see the location and orientation of the game pieces as they fall from the top. The game pieces act as focus anchors, and the opacity level provides users immediate feedback on their performance. The Tetris game difficulty level adjusts to users' performance to ensure just enough stress to motivate players to improve their level of concentration control.

5.4 Flow and Meditation

In the state of Flow, intruding stimuli are kept out of our attention, and people experience a merge between action and awareness. Maslow described the state as the narrowing of consciousness where people give up the past and the future; this experience shares the same characteristics as a meditative state of mind [42]. In Thích Nhất Hạnh's book *The Miracles of Mindfulness*, he introduced concentration as the basic condition for meditation to occur. Meditation can only be successful if we build up a certain power of concentration, a power achieved by the practice of mindfulness in everyday life [43]. Csikszentmihalyi also suggested that yoga is one of the oldest and the most systematic methods of producing the flow experience [2]. In Karma yoga, people are encouraged to turn everyday routines into mindful moments. This practice states that there are only mundane states of mind and not mundane activities. The practice of mindfulness can lead people into the state of flow where there is a "transcendence of individuality" and "fusion with the world" [42]. This suggests that designing tools that help people achieve a meditative state of mind might help people get into

Flow. Another important characteristic of activities that allow for Flow is their clear feedback to the person involved. Non-contradictory and unambiguous feedback is essential for people to incrementally improve their skills against the goal. These ideas can be applied back to the design of meditation training applications. One big issue with training for meditation is the lack of clear feedback. It is difficult for people to achieve Flow via meditation if they are not able to continuously adapt their techniques based on their performance. This challenge could be addressed by closing the loop between a person's meditation level and his or her efforts. The following design concepts use neurofeedback based relaxation mechanisms to help people achieve a meditative state of mind.

Design Concept 1 – Relaxation Body Scan

A multi modal meditation facilitation tool that help people practice the body scanning technique by incorporating EEG powered effectiveness feedback with augmented reality displays.

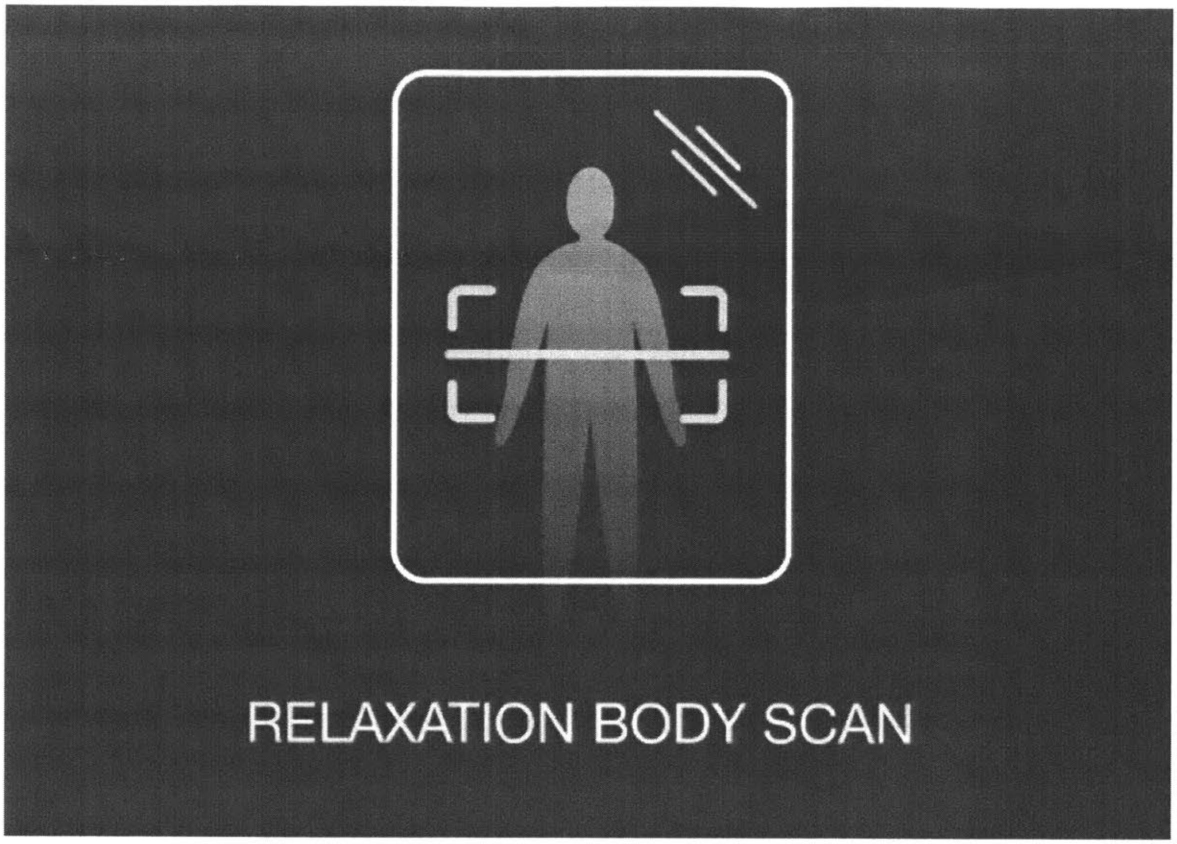
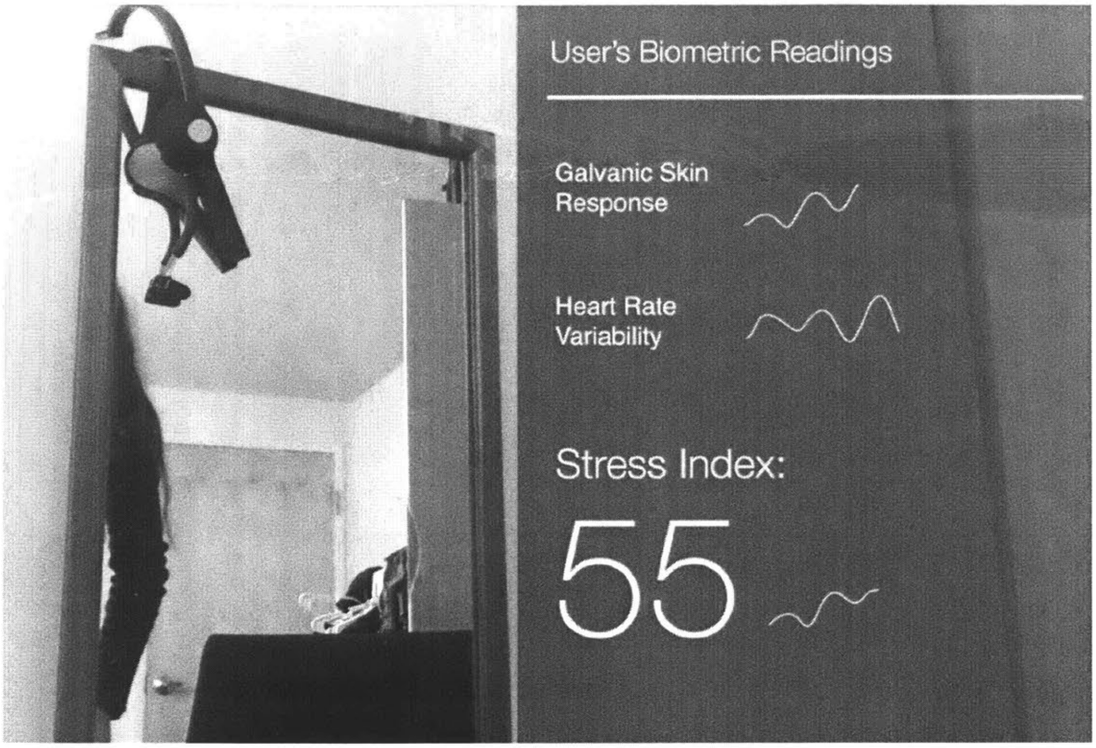


Figure 24. Relaxation Body Scan – Overview.

Body scanning is a meditation technique that helps people relax. Beginner minds tend to drift off before they are able to finish scanning their bodies mentally. They tend to have difficulty going through the exercise in a steady and controlled manner. The relaxation body scan tool provides a visual anchor and feedback for the scanning exercise. The virtual scanner overlay will move through the reflection of the user's body in a controlled speed, it will restart from the beginning if the EEG sensor detects a suboptimal meditation level. It also externalizes users' biometrics and stress level in real time, so they can see the effects of their meditation practice and adjust their techniques accordingly.



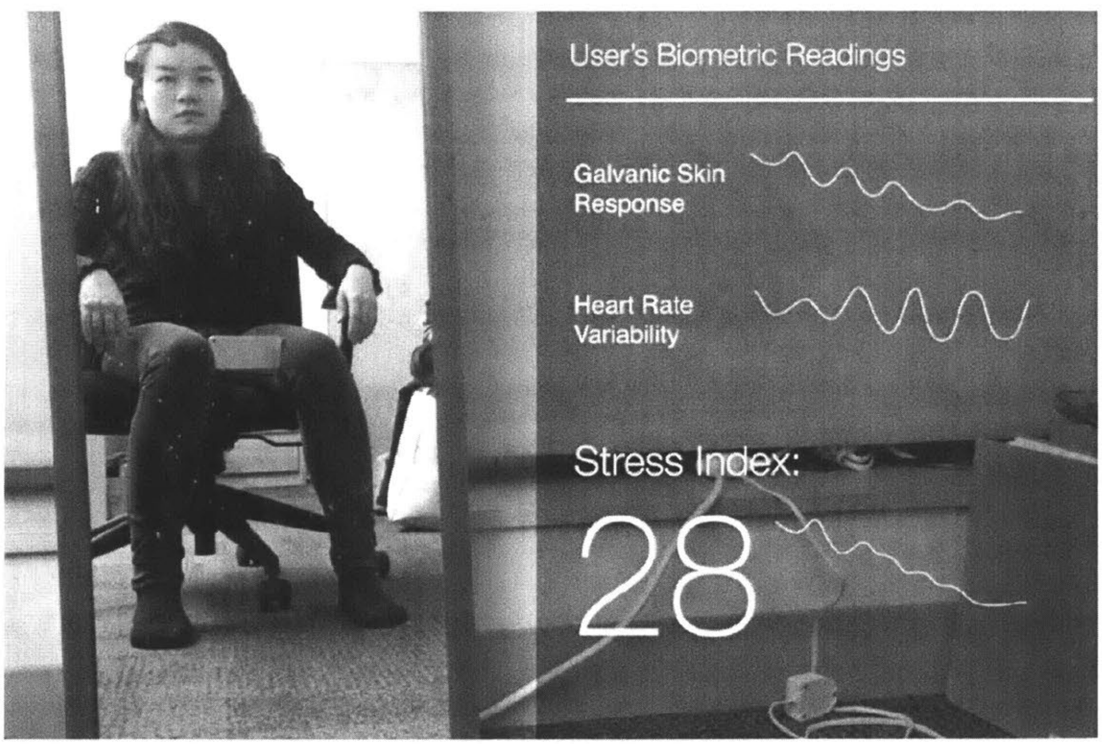


Figure 25. Relaxation Body Scan – User Experience Video Screenshot.

Design Concept 2 – Breathing Guide

Achieve a relaxed state with biofeedback driven VR breathing exercises that guide your breath to match a suggested breathing pattern.

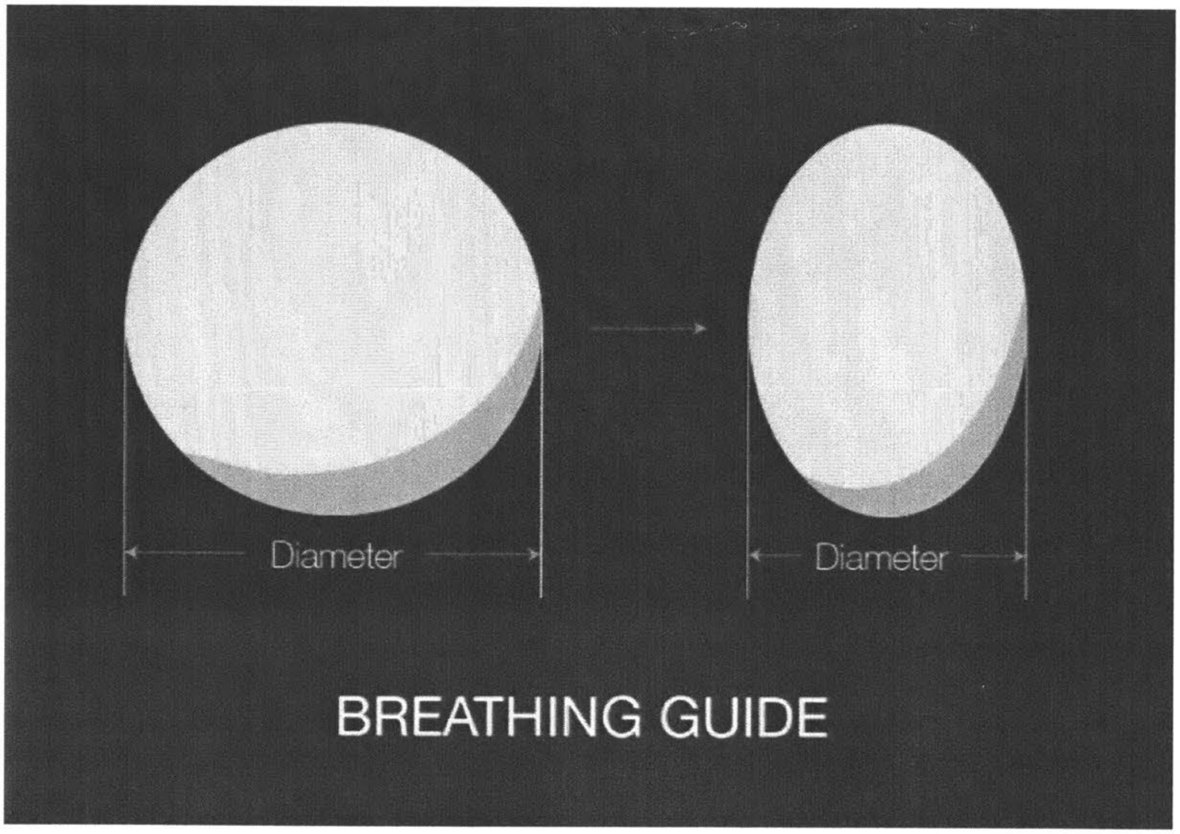


Figure 26. Breathing Guide – Overview.

Learn relaxing breathing techniques through an adaptive VR environment. The system uses conductive rubber cords to sense users' breathing patterns and construct virtual environments based on their breathing patterns. It displays an object that "breathes" slightly slower than the user's current breathing rate to nudge them towards the desired pattern. This helps users achieve a more relaxed state as they sync the movement of their environment to the movement of the guiding object.

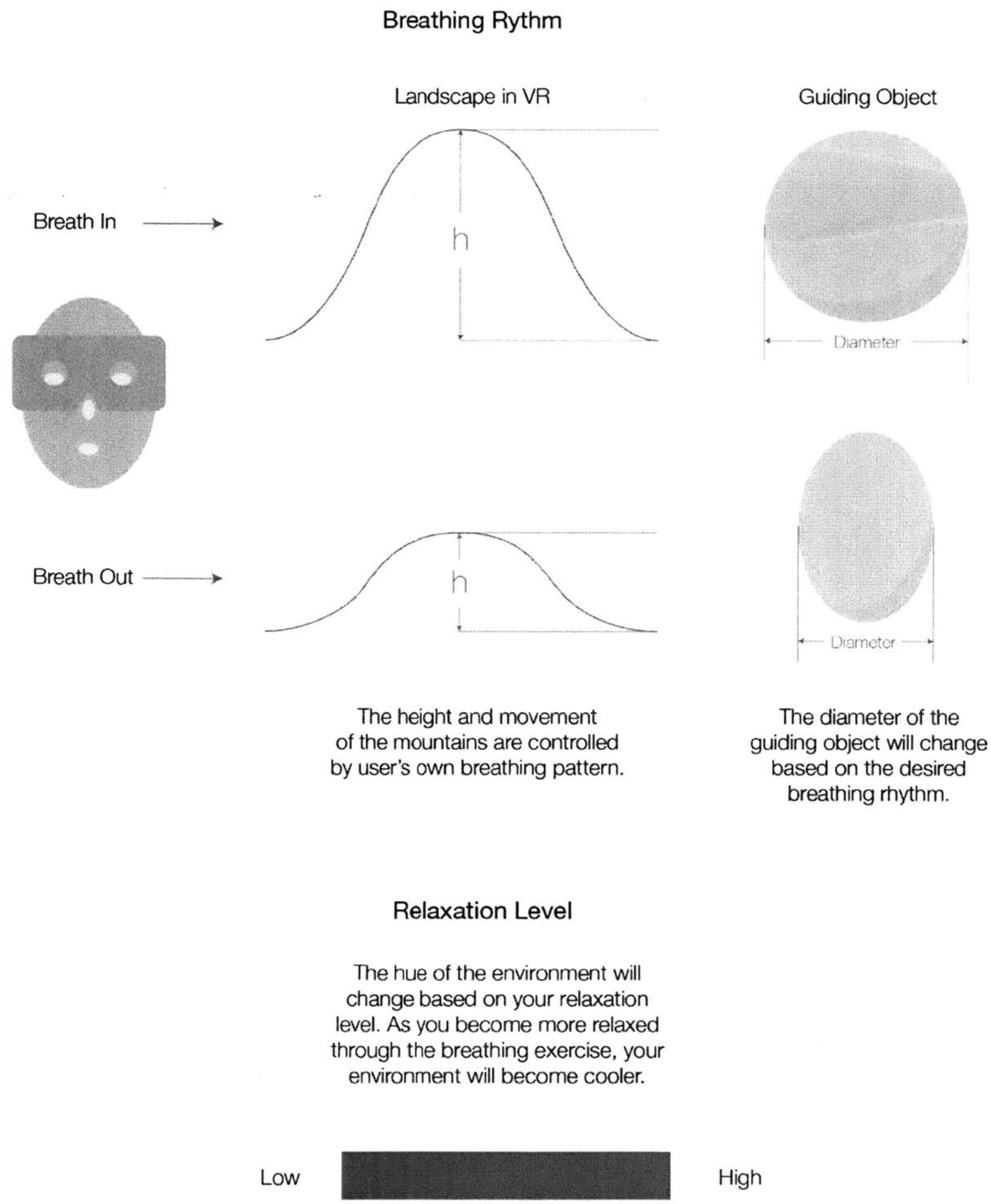


Figure 27. Breathing Guide – Game Mechanism.

5.5 Flow and Creativity

The state of Flow is often described by artists when they are completely immersed in the moment on stage. In the Beyond Boredom and Anxiety book, Mihaly Csikszentmihalyi quoted an outstanding composer's self description when he was writing music "You yourself are in an ecstatic state to such a point that you feel as though you almost don't exist. I've experienced this time and time again. My hand seems devoid of myself, and I have nothing to do with what is happening. I just sit there watching it in a state of awe and wonderment. And it just flows out by itself." [44] Of course, not everyone describe himself or herself as creative, and many people do not have the skills to enter the state of Flow with creative activities. What if machines could take care of the basic rules of a creative activity and lower the barrier of entering a creative state of mind? Many people have been interested in the idea of machine human collaboration in creativity-based activities. Margaret Boden explored the possibilities of computer's potential to be creative in her article "Creativity in a Nutshell". She defined creative ideas as surprising, new and valuable, she also clarified the difference between "psychological" creativity and "historical" creativity. The key difference between them lies in the perspective. "Psychological" creativity involves coming up with a surprising, valuable idea that is new to the person who comes up with it, where the "historical" creativity refers to ideas that are new to the human history [45]. We don not need the person to engage in "historical" creativity when we want them to experience Flow through creativity, they just need to be doing something that they have never done before. Since we are focusing on an individual's experience with a creative activity, what better ways than to express one's own emotional states? The design concept below illustrates a VR tool that encourages people to enter the state of flow by creating emotionally compelling experiences with the help of a machine collaborator.

Design Concept 1 – Emotive Brush

Co-create with digital tools that understands your emotional states

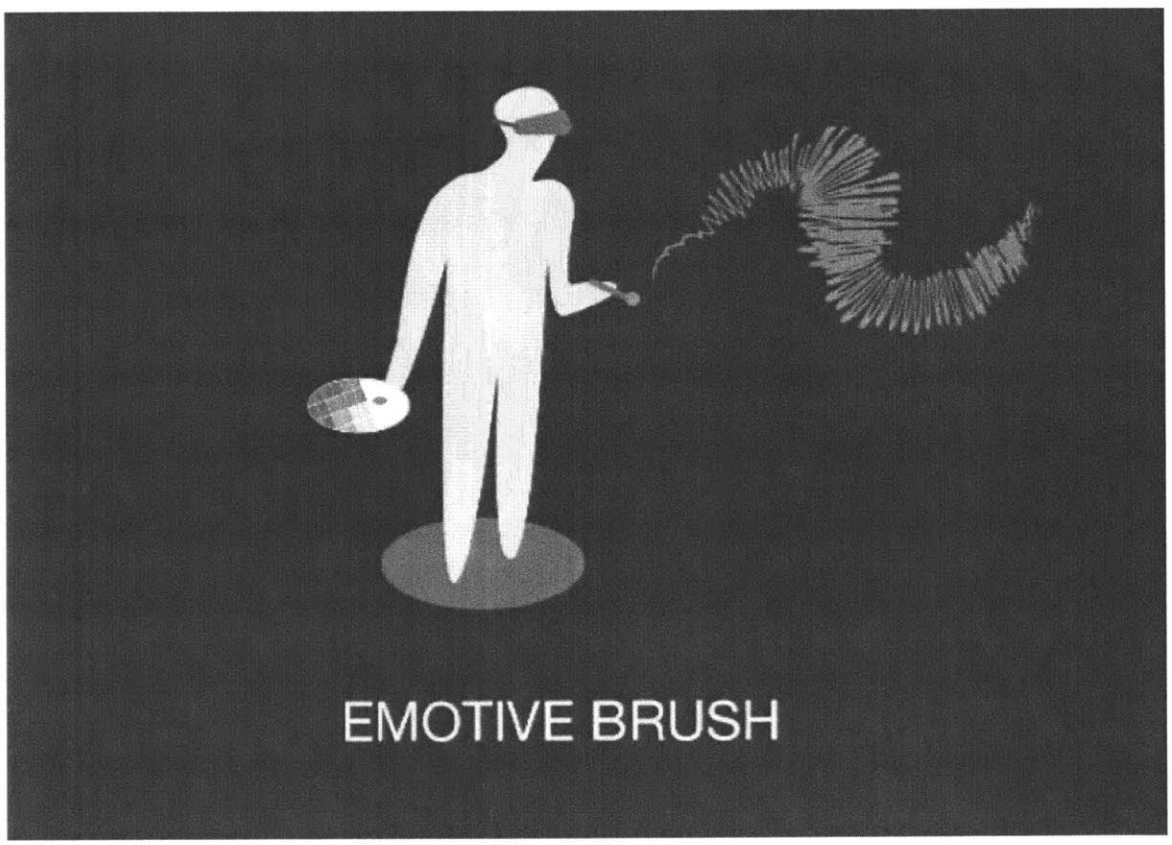


Figure 28. Emotive Brush – Overview.

Not everyone can channel their emotions through art as well as Monet or Picasso, what if we enable people with color palettes, brush qualities and base environments that externalize their emotional states? Emotive Brush is an immersive creative space where the machine's understanding of the user's emotional state is used to lower the barrier of creating emotionally compelling artworks.

The app uses VR technology as a way to bring people into a creative space shaped by their own emotional outputs. Based on sensor data and user's emotion calibration survey results, a default set of color palette; brush style and environment will be chosen. Users start in an environment that best matches their state of mind, as they paint onto the space, they evolve it with their emotional state. For example, the user started out feeling frustrated and got a congested street as the base environment, but it turned into a garden as he/she modified the space. Users can move onto another space by opening a virtual door, which acts as a refresh button, where users are given a new set of color, brush and environment based on an updated emotional reading. Their previous space will be saved into a journal and it can be revisited in the future.

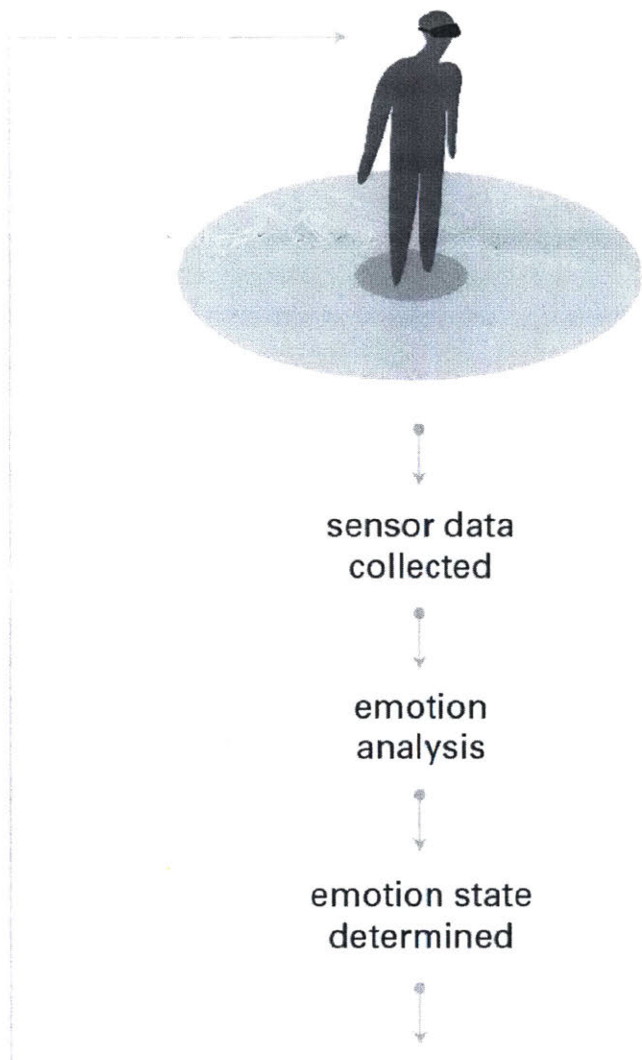


Figure 29. Emotive Brush – User Experience (part 1)

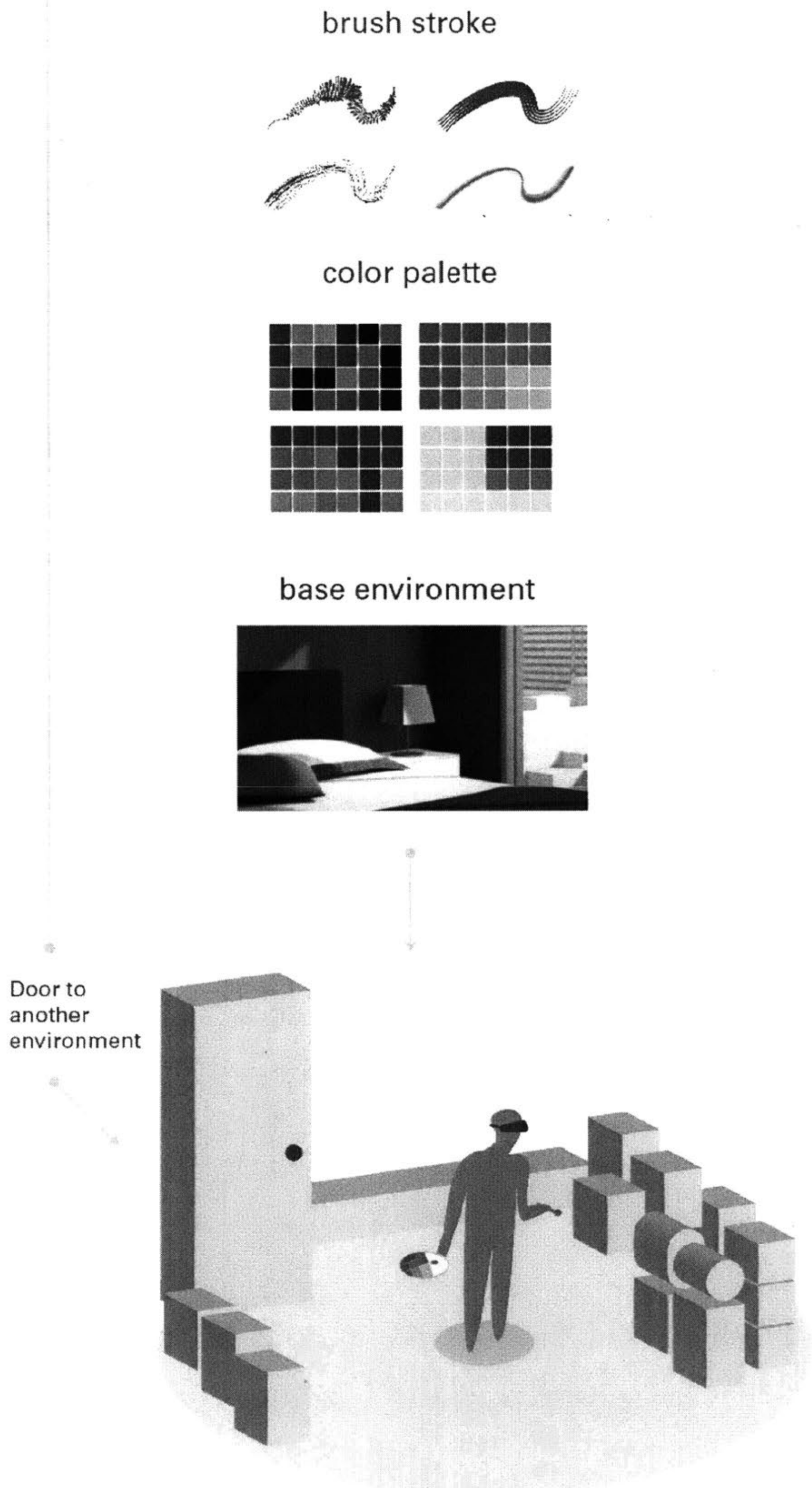


Figure 29. Emotive Brush – User Experience (part 2)

Emotion Journal and Sharing

Users can revisit their emotion journal by going back in space and time, or share and visit other people's environments. The spaces they created will be saved along a timeline as shown below, and the general emotional state of each space is expressed through color and texture. Users are able to get a general sense of how their emotional states have evolved with each new session on the same day. They can also zoom in and out to revisit a particular space they created or get an overview of their emotional fluctuation over a week, month or year.

In addition to sharing their journal, they could also draw with others, with each person bringing a unique set of palette and brush set. They might start at very different emotional states, but their pallets might converge as they sync with each other while create in the same space. This might be an interesting activity to do before verbal communication.

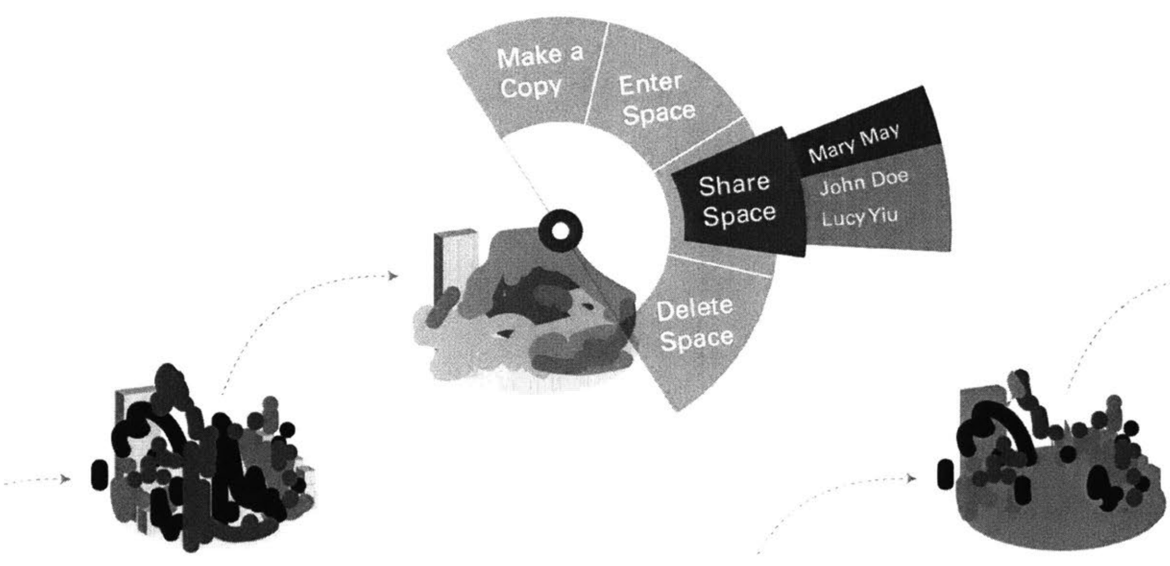


Figure 30. Emotive Brush – Menu Options.

Weekly View

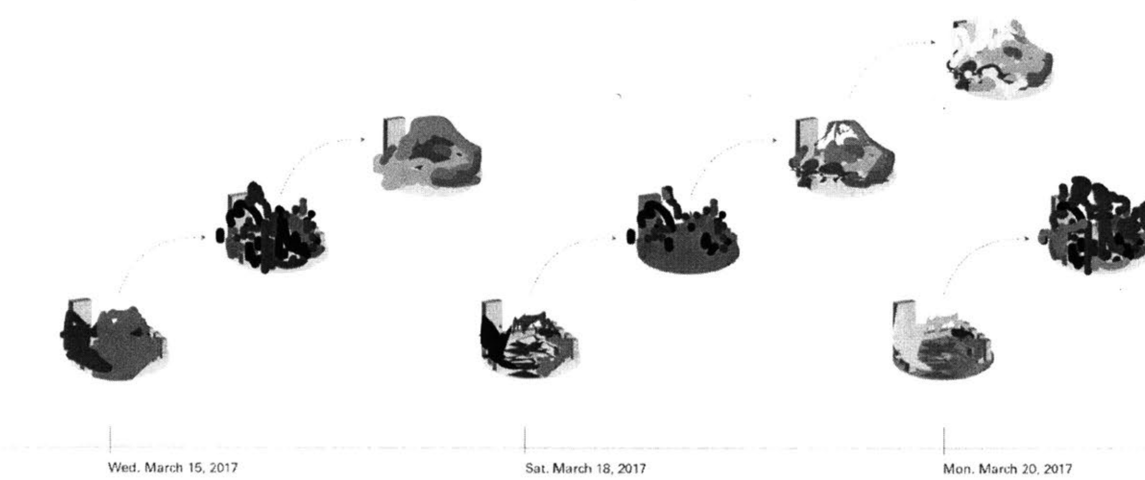


Figure 31. Emotive Brush – Weekly Summary View.

Monthly View

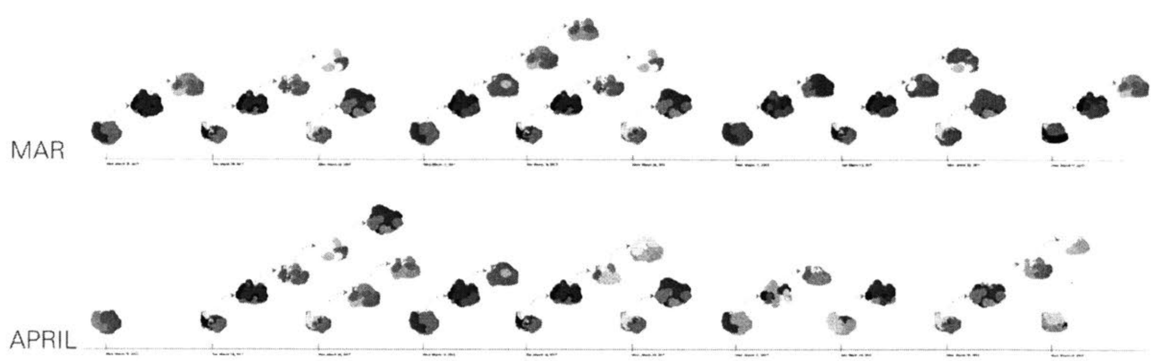


Figure 32. Emotive Brush – Monthly Summary View.

Emotion Calibration – Color

Through a survey, users are given a baseline color palette; they're asked to change the colors if they feel other colors better matched the emotion associated with the word presented. They can pick the same color for multiple squares; this is to take proportion into consideration.

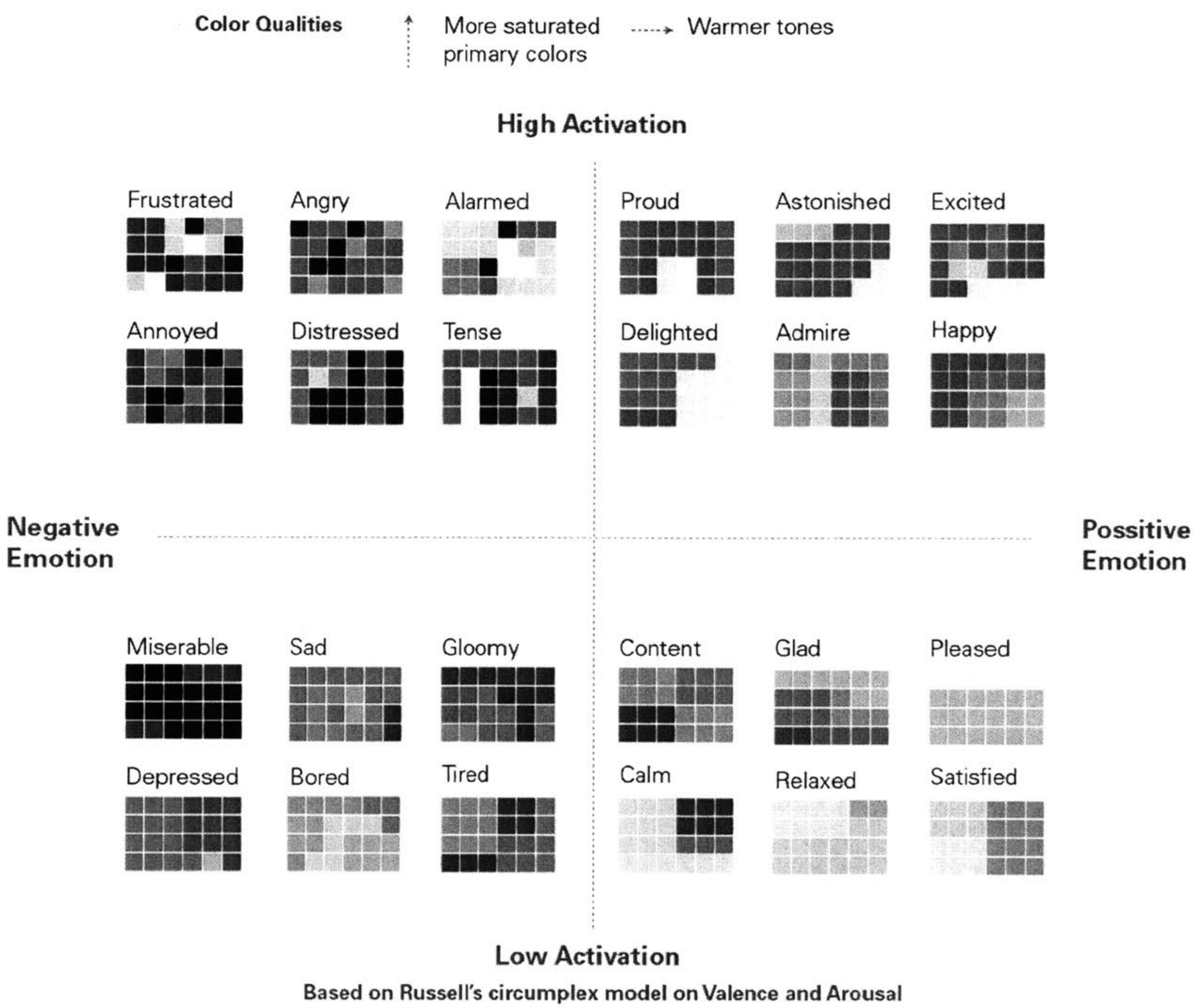


Figure 33. Emotive Brush – Color Calibration.

Emotion Calibration - Brush Stroke

Users are given a set of brush strokes, and they are asked to connect each stroke with a word that best represents the feeling of the stroke. Each stroke can only be associated with one word. An example of 2D representations of 3D brushes is shown below. Animations will be added as well.

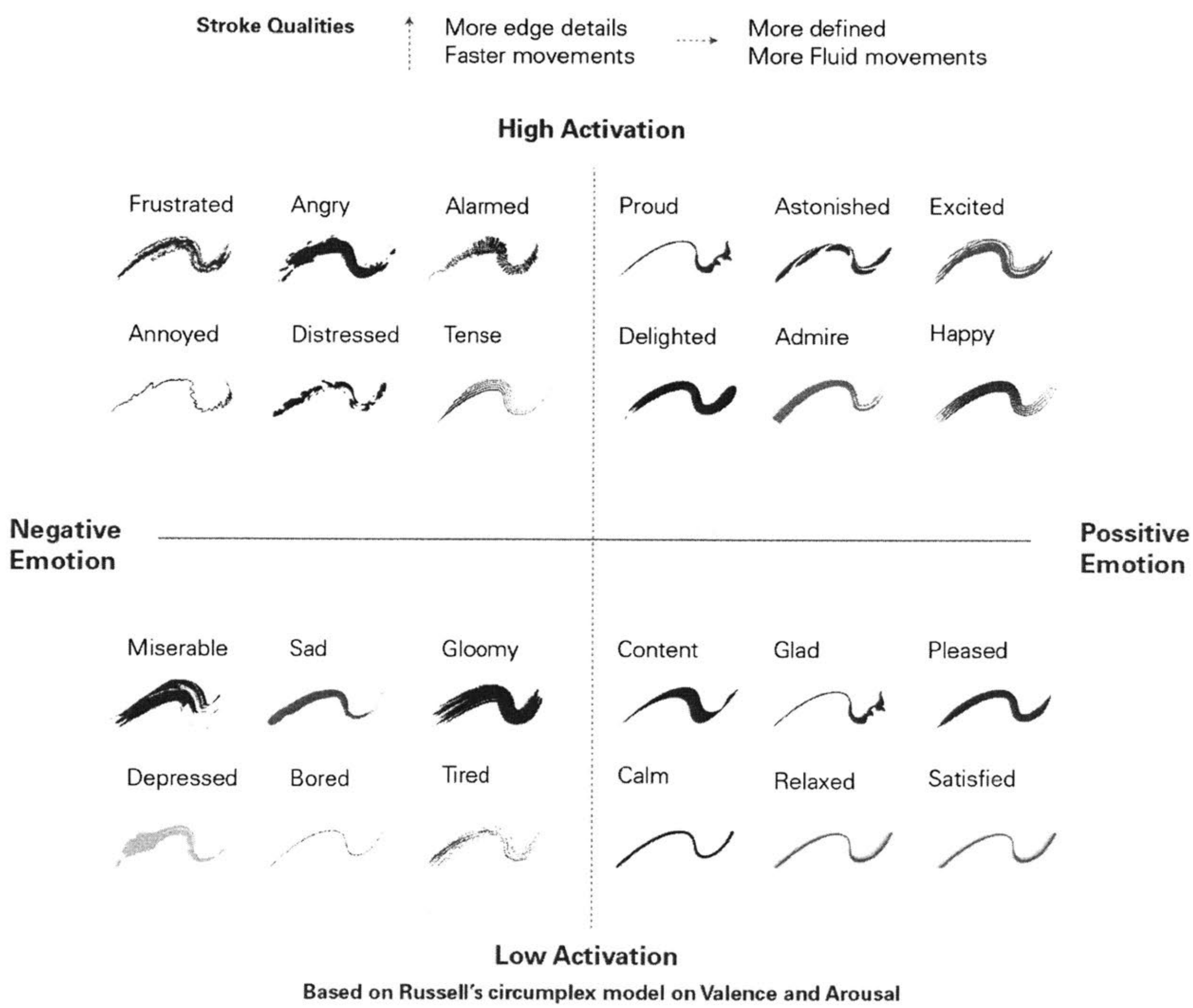


Figure 34. Emotive Brush – Brush Stroke Calibration.

Emotion Calibration - Base Environment

Users are given a set of environments and they're asked to match the environment with a word that best represented the feeling of that environment. Each environment can only be used once.

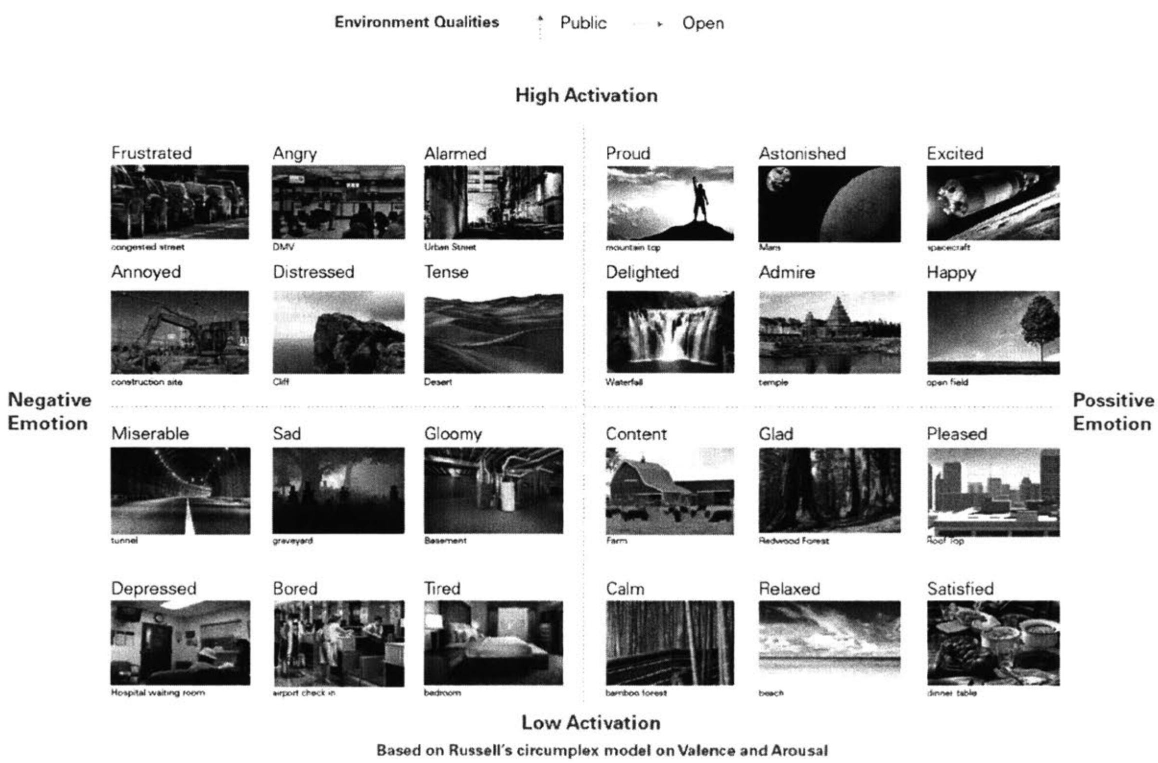


Figure 35. Emotive Brush – Base Environment Calibration.

Design Concept 2 – Digital Steel Ball

Hacking the wake to sleep transition for creativity

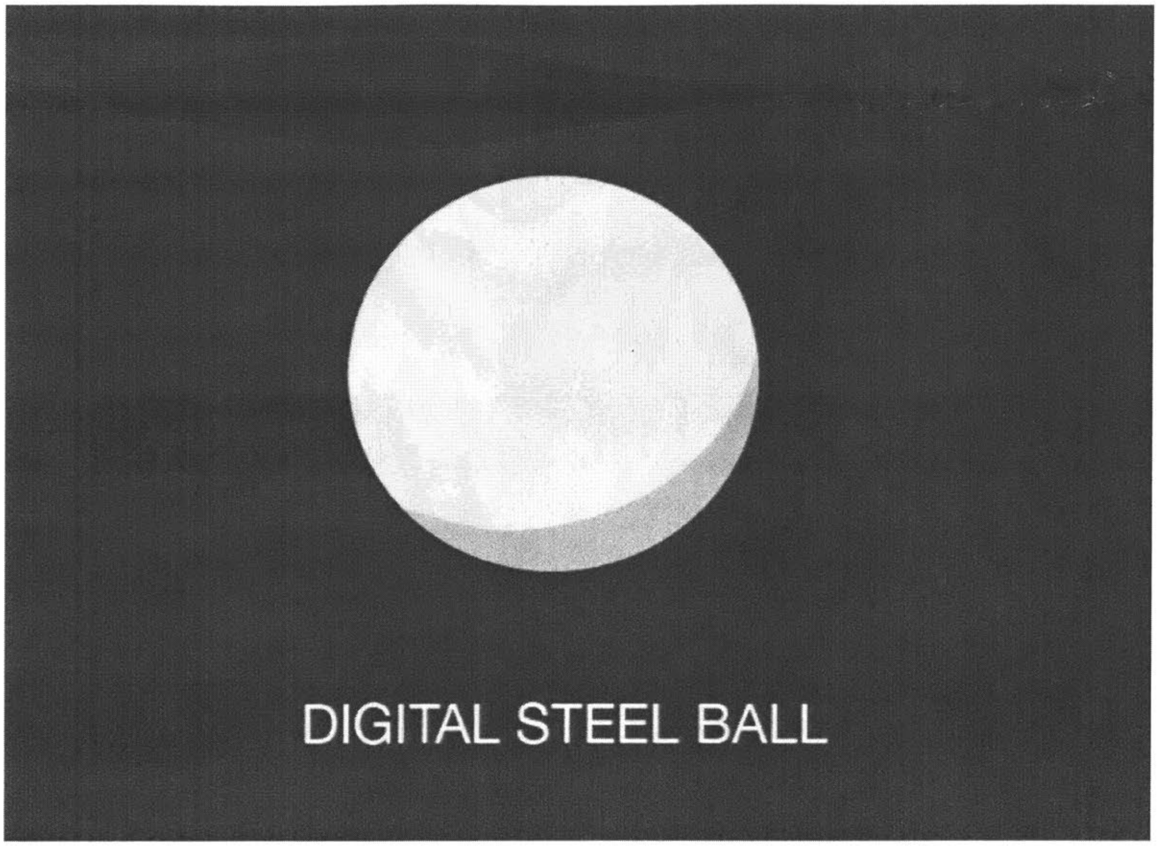


Figure 36. Digital Steel Ball – Overview.

Leverage our uninhibited free association abilities during hypnogogic sleep to help us solve problems creatively.

This project was developed in collaboration with Ishaan Grover and Adam Horowitz. Ishaan worked on the EEG signal processing and sleep spindle detection algorithms, Adam contributed the neuroscience foundation for the project, and I worked on the digital and physical product as well as the user experience.

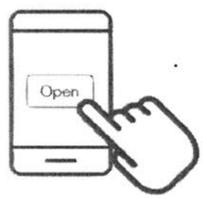
Thomas Edison would take a nap while holding a steel ball, as he drifted off and relaxed, the ball will drop to the ground and wake him up. He used the ball as a way of staying in stage one sleep (hypnagogic sleep) and he was able to wake up with many new ideas for research. Hypnagogic sleep is correlated with enhanced creative ability, heightened suggestibility, illogical and fluid association of ideas, loosening of ego boundaries and anxiety reduction [46]. Can we come up with a better technology than the steel ball? In the interest of our neighbors and our floors, we could use EEG sensors to determine people sleep stages, and wake him or her up with a pre-recorded inception words. In addition to the sleep state detection functionality, we could incorporate brain entrainment techniques to quickly get people into stage one sleep. Theta waves (4 to 8 Hz) are typically associated with the hypnogogic stage. We could flash lights and play beats at a frequency between 4 to 8 times per second to lead people into the hypnogogic state. Furthermore, we could incorporate voice-recording capabilities to facilitate the documentation of solutions and ideas people come up with while in hypnagogia.

User Scenario 1: Using photoentrainment to enter hypnagogia

After hitting roadblocks, user decides to continue solving problems during a nap.

User Actions:

1. Initiates the app

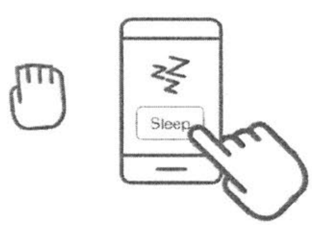


User opens the digital steel ball app on both their computer and their phone.

2. Records keywords

User records the keywords he / she wants to hear during the current nap session.

3. Starts photoentrainment



User sets up the digital steel ball, then initiates the photoentrainment function in the app.

System Actions:

The desktop computer app establishes connection with the phone app.

The phone app turns on the microphone and begins to sample voice data.

The desktop app begins to listen for signals from the digital steel ball via serial port. The mobile app begins to play the photoentrainment video full screen.

User Actions:

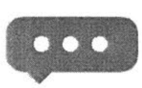
4. Prepares to nap

User inserts the phone into the sleep mask before putting it on, and finds a comfortable position to sleep.

5. Enters Stage 2

User releases the digital steel ball, which indicates the beginning of sleep stage 2.

6. Records ideas



After hearing the recordings, the user begins to verbalize ideas they thought about during sleep stage 1.

System Actions:

The desktop app detects the change of state from the digital steel ball, and sends a command to the mobile app to playback the keywords recorded by the user, it also initiates the voice recording function on the mobile app.

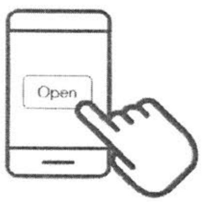
Figure 37. Digital Steel Ball – User Scenario 1.

User Scenario 2: Enter hypnagogia naturally for creative problem solving

Right before going to sleep, the user wants to use the digital steel ball app to generate more ideas for her project.

User Actions:

1. Initiates the app

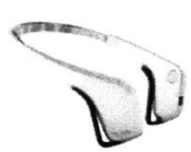


User opens the digital steel ball app on both their computer and their phone.

2. Records keywords

User records the keywords he / she wants to hear during the current nap session.

3. Puts on the Muse headset



User puts on the Muse headset and establishes a connection with the app.

System Actions:

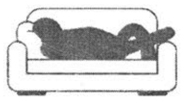
The desktop computer app establishes connection with the phone app.

The phone app turns on the microphone and begins to sample voice data.

EEG sensor begins to send data to the desktop app.

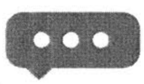
User Actions:

4. Stage 2 Detected



User drifts into stage 2 sleep.

6. Records ideas



After hearing the recordings, the user begins to verbalize ideas they thought about during sleep stage 1.

System Actions:

The desktop app detects sleep spindles from the EEG data. To bring the user back to stage 1 and think about the topic designated by the user, the app plays the user recording. It also turns on the voice recording functionality.

The mobile app establishes a new file and names it with the beginning and end time of the recording

Figure 37. Digital Steel Ball – User Scenario 2.

Application User Experience Design

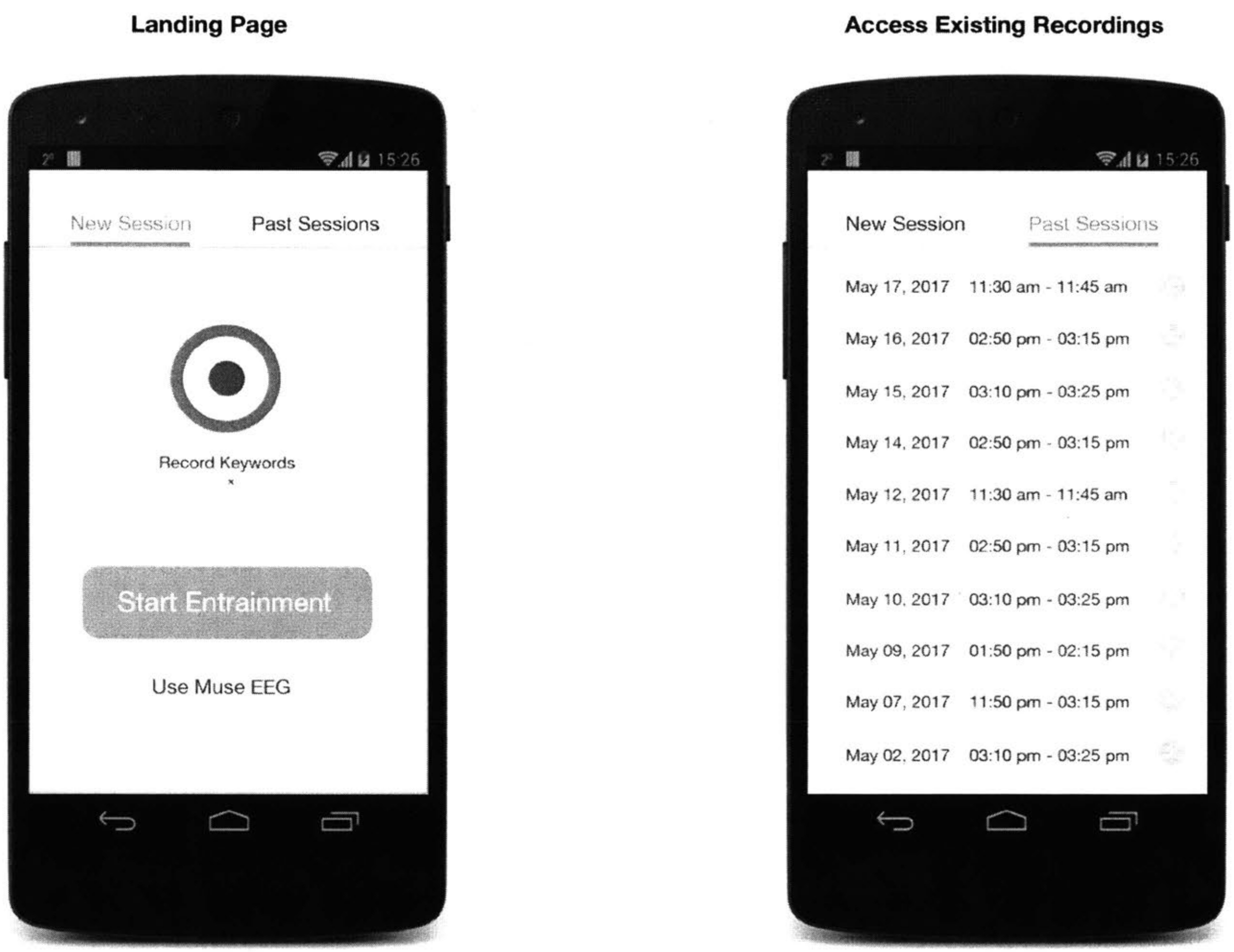


Figure 38. Digital Steel Ball – UX Screen Design.

Sleep Mask Industrial Design - Drawings

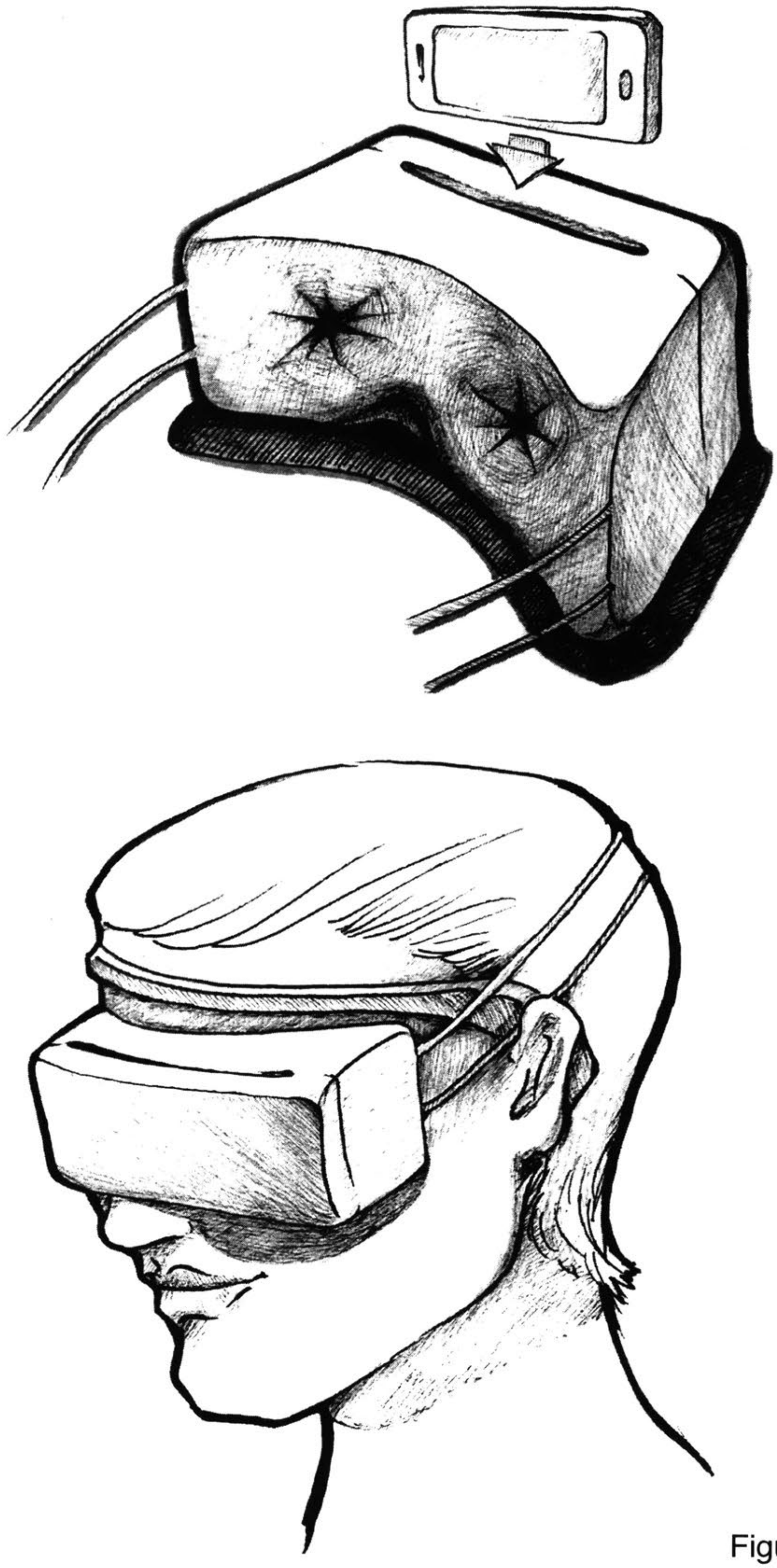


Figure 39. ID Drawings

Sleep Mask Industrial Design – Prototype

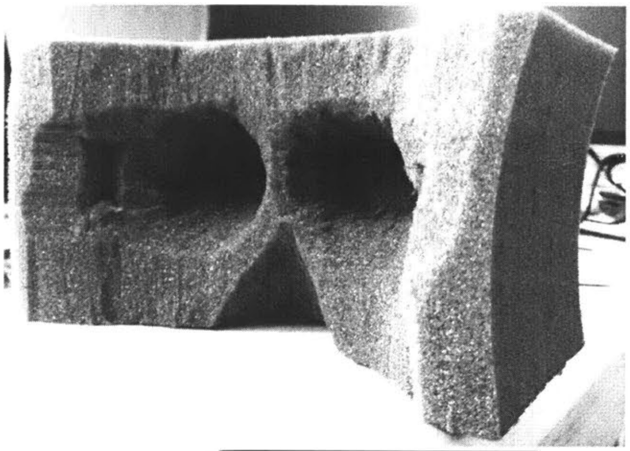
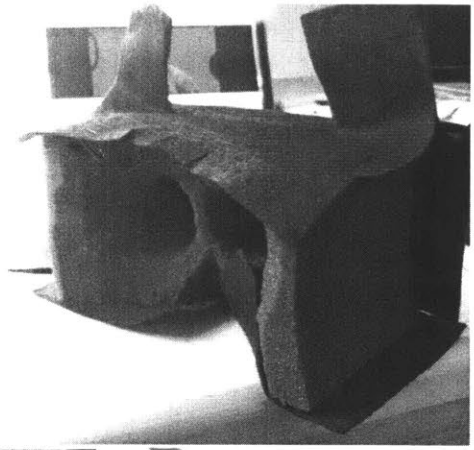
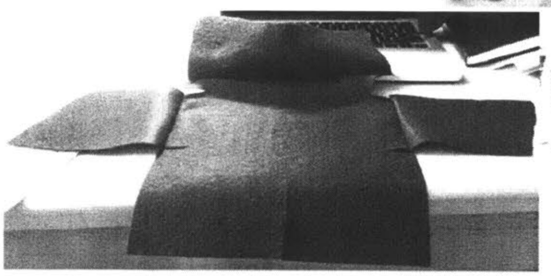
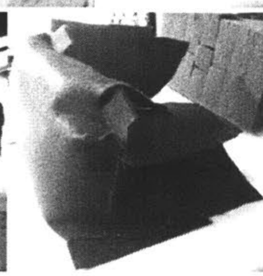
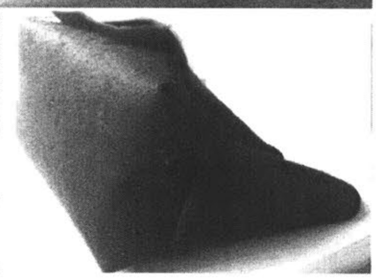







Figure 40. Sleep Mask Prototype

Digital Steel Ball Industrial Design – Prototype

Figure 41. Digital Steel Ball Prototype

Chapter 6

Staying in Flow

6.1 Keep Distractions Away

The state of Flow is difficult to achieve, and we definitely want to help people in the state for as long as possible. When people are in the state of Flow, we need to do our best to keep potentially intruding stimuli out of their attention to ensure concentration. The detail concept below leverages user's continuous and parallel subconscious input to drive the behavior of a possible operating system notification layer.

Design concept 1: Responsive Notification

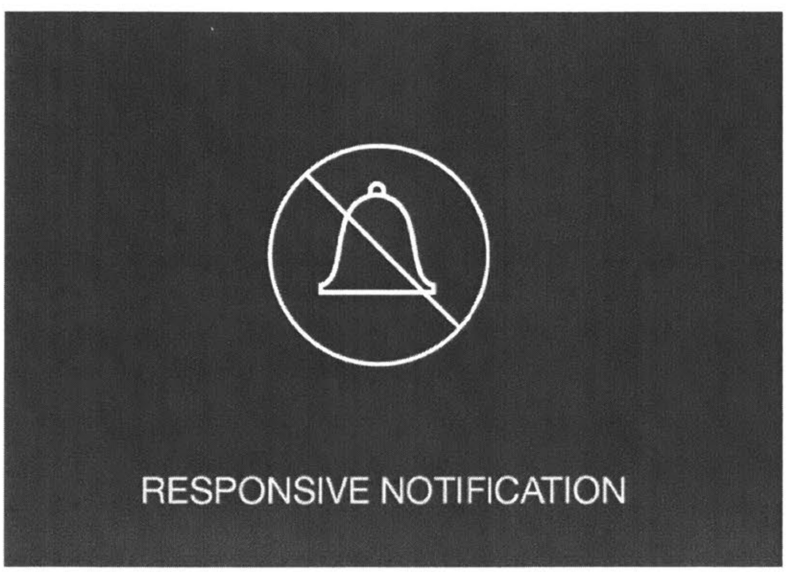
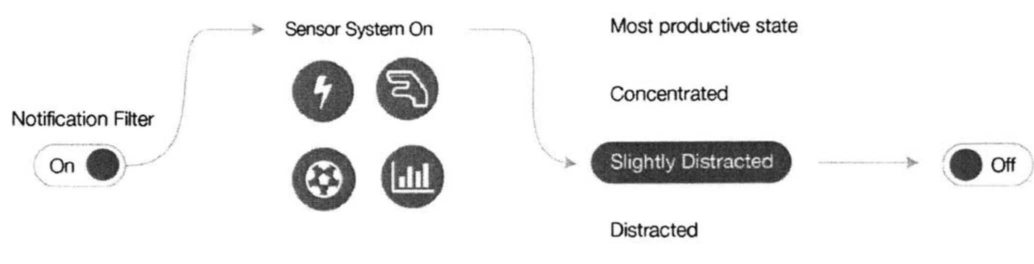


Figure 42. Responsive Notification – Overview.

The Responsive Notification system depends on user's posture, concentration level and emotional state. It eliminates distractions, reduces notification anxiety and enables a peace of mind by filtering notification messages based on user's biometrics.

The dilemma of wanting to turn off notifications to concentrate, but still feeling worried about missing that important message or an expected call often leaves people distracted. People end up either checking notifications when "Do Not Disturb" is on, or not enabling the functionality all together. This concept aims to create a responsive notification system that adjusts the level of message filtration based on users' concentration levels, postures and other emotional state signifiers. The system will provide users a message ranking system based on a filtration level corresponding to users' continuous physiological data inputs. Users will be able to personalize the message type based on the platform and/or message sender.

User Actions: Normal use



1. Users turn on the responsive notification application on their desktop.

2. The application turns on the EEG sensor and the other emotion tracking sensors.

3. The notification level adjusts based on users' concentration level, posture, and movement.

4. Users turn off the notification application.

User Actions: Configuration

1. Drags and drops the applications under each prioritization level.

2. Sets any exceptions by clicking on the Add button.

3. Selects the application from a dropdown

4. types in the name of the sender.

Prioritization Levels - adaptive based on user specific productivity level distribution

Most productive
EEG concentration:
90% above optimal
Posture:
upright
Movement:
no fidgeting

Concentrated
EEG concentration:
70% above optimal
Posture:
normal
Movement:
infrequent fidgeting

Slightly Distracted
EEG concentration:
50% above optimal
Posture:
slightly hunched over
Movement:
some fidgeting

Distracted
EEG concentration:
20% above optimal
Posture:
hunched over
Movement:
frequent fidgeting

Applications to prioritize

Slack

Facebook

Messages

Mail

Figure 43. Responsive Notification – Detailed Design.

Design concept 2: Responsive Image Quality Filter

Screen quality adapts to continuous sub-conscious user inputs to help them stay in the Flow.

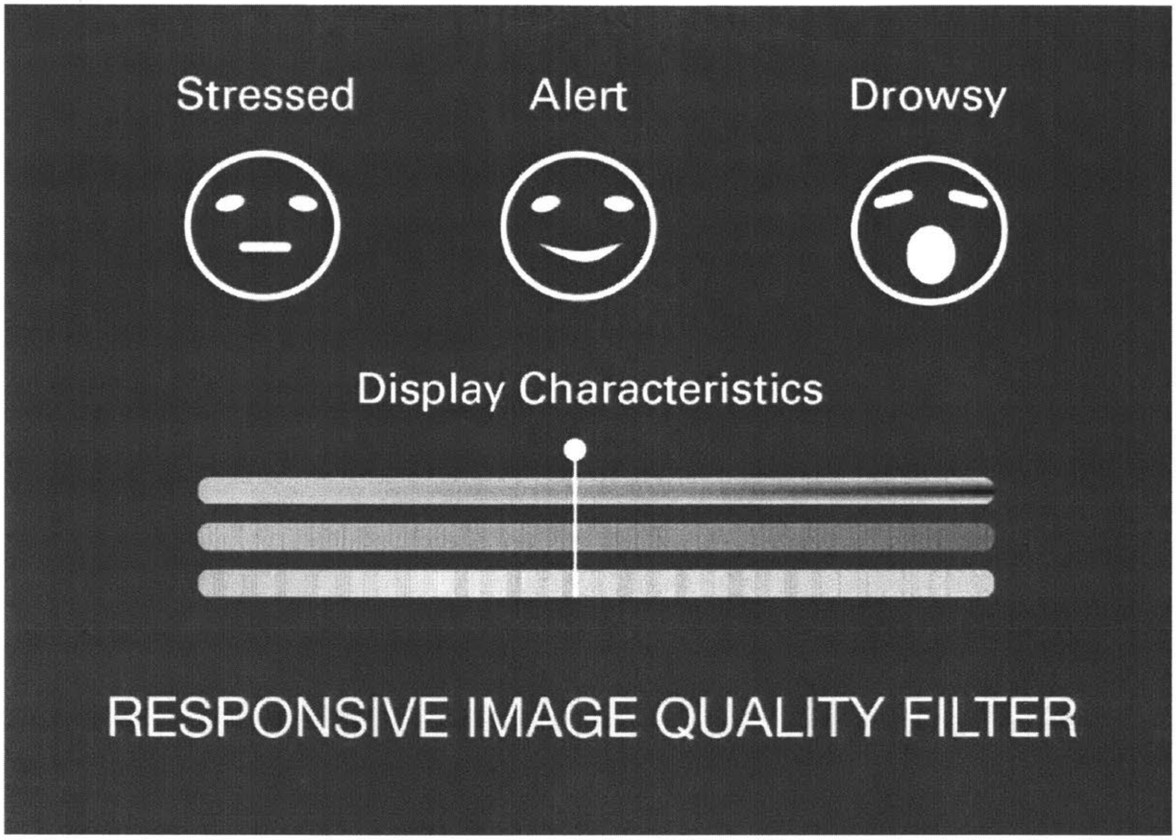


Figure 44. Responsive Image Quality Filter – Overview.

Currently, devices don't adapt to people's changing situation awareness and emotional states, people at risk of dropping out of flow face the same display quality as those who are deeply engaged and performing at their optimal level. What if the display characteristics adapted to individuals' Flow index to keep them engaged for longer periods of time? The responsive image quality filter aims to change display qualities such as hue, saturation, and contrast to keep users in the flow without their active attention.

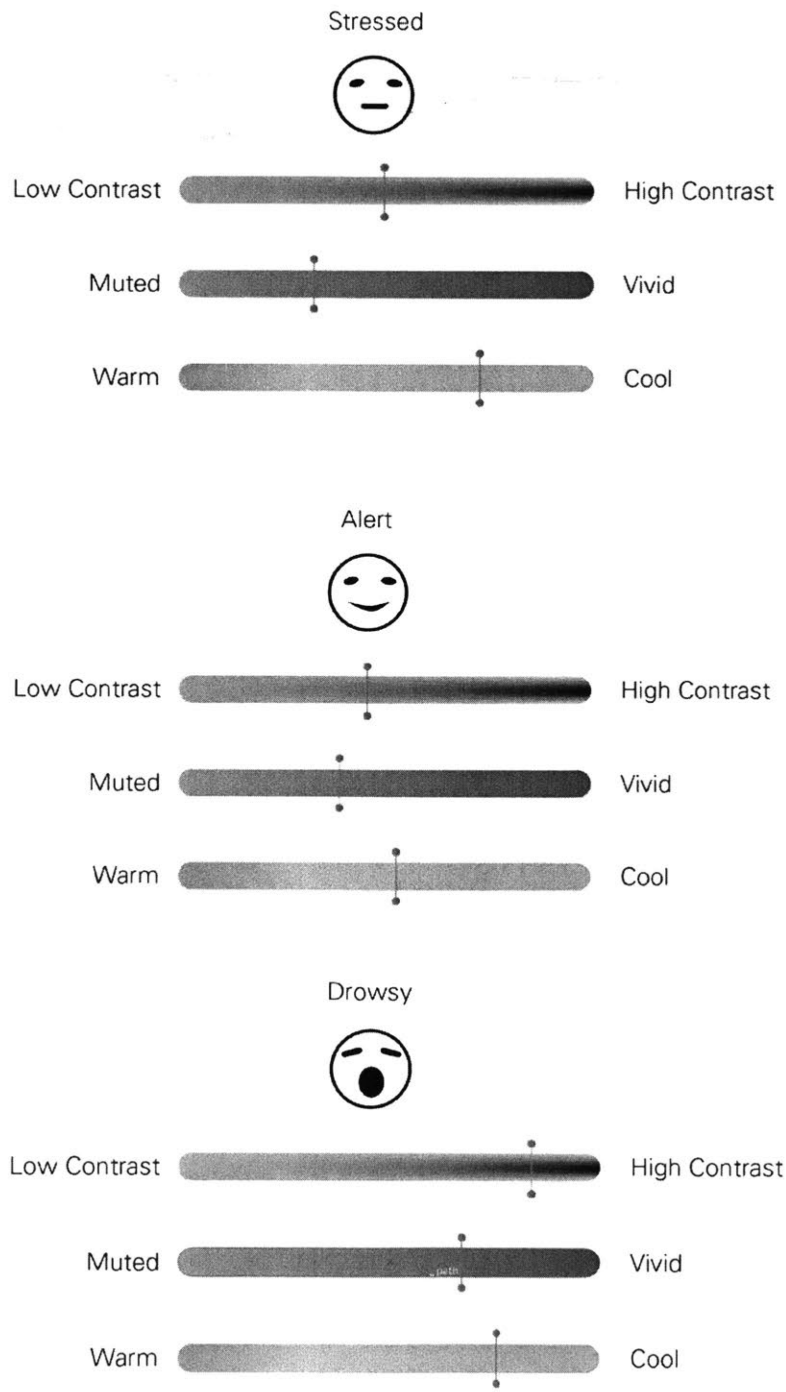


Figure 45. Responsive Image Quality Filter – Example Settings.

6.2 Encourage a Learning Mindset

In recent revisions, Csikszentmihalyi claims that Flow is experienced when both the challenges and skills are high. When an activity presents constant challenge, there is no time to get bored or to worry about the future, and the person in such situations achieve effortless focus by rising to the challenge with an appropriate level of skill [30].

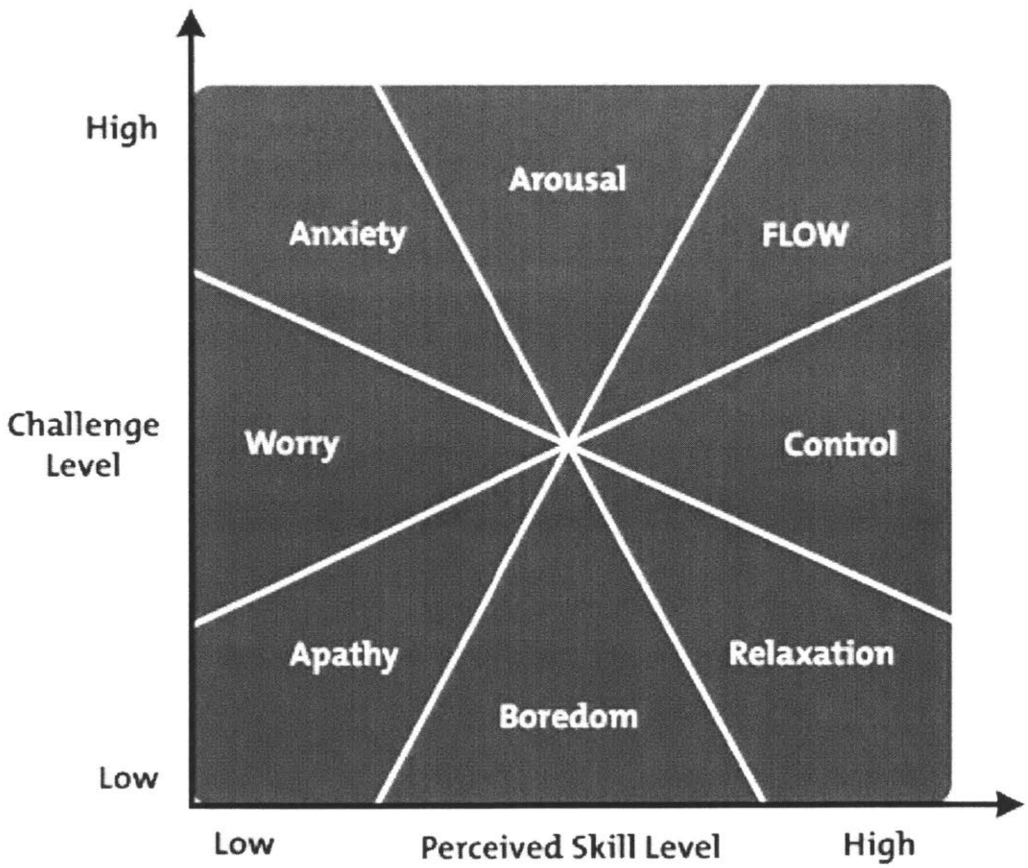


Figure 46. The Flow Model published by Csikszentmihalyi in 1997.

How might we design products that encourage users to develop their skill levels in face of new challenges? Activities that allow for the state of Flow in the present moment might make people feel the sense of control and relaxation in the next moment, eventually, people reach the sense of boredom and apathy. We need the challenges to continuously evolve with people's skill improvements, so they do not lose interest as described above. At the same time, the difficulty level needs to be just out of reach, otherwise people will experience anxiety, worry and eventually develop apathy as well. We need to think about ways to encourage a learning mindset while presenting challenges that adapt to users' skill levels.

One of the pre-conditions for people to continue developing new skills is a learning mindset. When people push themselves to gain more knowledge by challenging their comfort zone, they inevitably will encounter setbacks and failures. Those who approach failure with a learning mindset tend to succeed more than those who feel that their failure is the result of a native ability. Anderson and Jennings did a study with two groups of people where one group was primed with the learning mindset and the other were led to believe the result of their actions were caused by a stable factor like intelligence. They were able to prove that those who believed success is a result of effort and strategy were more likely to overcome failure and try things again, they were more likely to expect future success than those who believed that success was a matter of inherent ability [47].

How might we favor effort rather than ability through the design of virtual and augmented reality environments? One approach is to design interfaces that evolve with the user ability. A user might need a lot of hand holding through voice and visual guides when they first encounter an environment, so we might design a first time user experience that humanizes the tutorial into something similar to a tour when a guest visits. We might also consider testing user's understanding of the virtual space by having them complete tasks at varying difficulties, and adapt the experience based on their performance. Instead of telling them that they have failed, we should present them an overview of how far they have come since when they started interacting with the environment, why they have failed and how they should improve it. This approach solidifies the learning thus far, provides clear feedback to the user and gives users strategies to improve, which puts them in a learning mindset. We are more likely to encourage someone to continue exploring and perfecting their skills if we show them their progress and give them a clear roadmap forward.

6.3 Personalized and Adaptive Challenges

In addition to getting users into a learning mindset, we also need to adapt the challenges so users can balance their skills with the tasks we present them. At the simplest level, we need to enable functionalities that reward users who took the time and effort to improve their skills. The rewards could manifest in users saving time and effort in accomplishing the same goal, or the ability for them to perform more complex activities. We need to design experiences for both the novice users and the experts. Designers need to move beyond slapping a first time user experience tutorial on a new software product and call it done. We need to take the time to break each interaction down into smaller components, and reconstruct a dynamic interaction pattern that could supports a gradient of skill levels and creates a smooth path from being a beginner to an expert user.

Chapter 7

Conclusion and Future Work

7.1 Application Areas

Productivity applications and the platforms that support them can benefit greatly from these techniques, as can applications used for content creation—whether writing, programming, or painting. Helping users prioritize and switch between high and low attention tasks can be very beneficial, especially at the platform level. Many productive people do things like avoiding meetings and answering emails during their most productive times of day, and this is essentially a way of moving the burden of managing this task from the user to the system so the person can focus on what they are actually trying to do rather than fighting distractions (which often come from the system in the first place).

While any sort of productivity application can arguably benefit from these ideas, high stakes areas where VR and AR technology is increasingly being integrated stand to benefit the most. Operating rooms are currently full of alarms and displays, and as surgeons start to rely on robotic assistive technologies to perform surgeries more, they are faced with another complex machine to manage, and because they are now using a screen to control their tools, it is all too tempting for systems designers to show alerts and error messages along with their view of the surgery. Finally, the same challenges apply in semi-autonomous cars and aircraft with the added challenge of keeping pilots and drivers mentally engaged and present so they can take over if necessary. All these areas could benefit greatly from interfaces that adapt to keep people engaged, and help to focus attention rather than fragmenting it.

7.2 Word of Caution

Creating experiences that draw people into a state of Flow is hard, but when it is accomplished, the user is essentially losing agency over whether to stop or not. This means that applications must be designed with the user's best interests in mind. While a writing tool that helps users maintain Flow for long periods of time is desirable, and a similar productivity tool that helps users get more work done might be acceptable, applying these techniques to the design of something like a slot machine is questionable at best. Ultimately, the users of the system must retain full control over the outcome of their interactions with machines, especially for subconscious / subliminal interfaces. They do not have to know when the subliminal interface is affecting them, but they need to have control over what the system is trying to achieve and why.

7.3 Final Words

As designers and developers contributing to the digital experiences of the future, we have an incredible opportunity to augment human capabilities through VR and AR. The design decisions we make today can have profound implications on how the future of human computer interactions plays out. Unfortunately, current business models based around providing free services and monetizing user data lead to experiences that optimize for engagement over everything else, including wellbeing and happiness. Every day, people are pulled in multiple directions as they interact with digital devices. Bright red badges on icons designed to compel attention, display ads that clutter the news articles they read, and the endless constantly manipulated stream of social media updates from ever-expending groups of “friends”. People are being put into an anxious state where their intentions are being challenged constantly, they could be doing what they are doing, but there are ten others things that seem to require immediate attention. On an individual app basis, these problems can lead to experiences that are effectively addictive and don’t actually improve people’s wellbeing or deliver other benefits. On a platform level, these tendencies are combined with a distracting clamor for attention that negatively impacts productivity and focus. All of these problems only get worse as digital technologies become more pervasive in people’s lives, and digitally mediated experiences become more immersive.

As we replace our physical spaces with digital spaces, we need to consider how humans perceive, process and interact with the world, and construct digital experiences that are truly humanistic. A humanistic interface respects selective attention and enables Flow. The command and control model where users have to consciously realize their intentions, translate them into commands that users think the machine could understand, input those commands and hope to get the right feedback. This type of interaction model is extremely slow in comparison to the interface humans have with the real world, it also demands one hundred percent of people's conscious attention. In physical interactions, people have access to inputs from the five senses, as well as conscious and sub conscious information processing power, which allow them to have continuous and parallel interactions with the environment. Designers and developers need to learn from this humanistic interface when designing for a Flow enabling interaction paradigm for virtual and augmented reality experiences.

Csikszentmihalyi's research on Flow was motivated by the ultimate quest for human happiness. It is our responsibility to ensure the mental and physical wellbeing of users who engage with our products. By nudging users into an implemental state of mind, we may help them on the journey of figuring out the strategies for accomplishing a goal. By enabling for concentration and meditation training, we may help people learn how to better control their attentional spot light, and by lowering the barrier to a creative endeavor, we are getting more people to engage with activities that will get them closer to the state of Flow.

Once they are in the state of Flow, the last thing we want to do is to snap them out of it with poor interface design choices. We need to continuously listen to the mental capability, physiological and emotional state of the user to adjust system level attributes that elongates the period of flow. Finally, we need to encourage a learning mindset and design adaptive systems that reward users who strives for skill improvement. This is just the beginning of the exploration towards bringing humanistic immersive digital design to the masses.

These principles and techniques can contribute to creating experiences that make people happier, more productive, and more fulfilled. While they work when applied to the design of individual applications, they can have the greatest impact when applied to the design of platforms. People's experience of an application is mediated by the platform it runs on, and so any individual application's ability to fully control the user's experience is inherently limited. An application might have a beautifully spare interface with adaptive feedback and all the necessary conditions for Flow, but this is meaningless if the platform allows other applications to pop up notifications. This is even more true for newly emerging platforms in areas such as AR and VR. The first generation of popular VR and AR content consumption platforms will have a significant impact on people's perceptions of how virtual and augmented reality products should work. Particularly for augmented reality where there is huge potential for the technology to become a constant presence in people's lives like smartphones are today, as designers and technologists we have both the responsibility and the opportunity to guide the evolution of the technology in a direction that creates a positive impact on people's wellbeing, in addition to augmenting their capabilities to become more productive and creative individuals.

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