Mental Health Interventions through Brain Wave Oscillations

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ABSTRACT

Brainwave entrainment is a method for inducing brainwaves to synchronize to the oscillations of an external stimulus. Computer and mobile displays provide a significant opportunity for non-obtrusive brainwave entrainment, as the therapy can be applied while the user is using the device normally, thereby obviating the need for active engagement from the user. To date, there is no prior HCI literature attempting to induce brainwave entrainment through external stimuli. Here, we introduce the concept in the context of HCI, describe the system development, detail several possible instantiations of entrainment interfaces, and describe user feedback from a preliminary user study. This work can ultimately result in a translational intervention which can be used in home and work settings.

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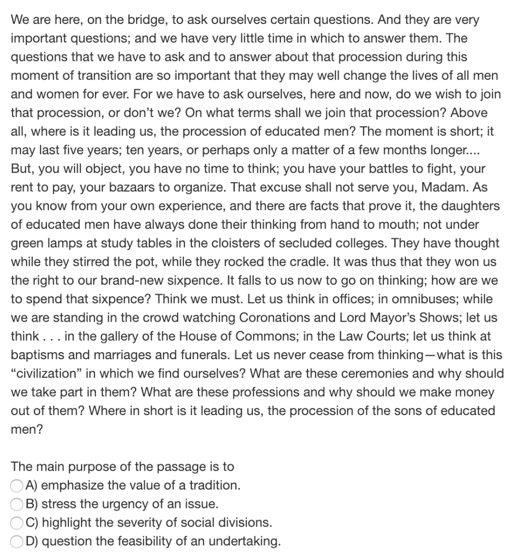

We are here, on the bridge, to ask ourselves certain questions. And they are very important questions; and we have very little time in which to answer them. The questions that we have to ask and to answer about that procession during this moment of transition are so important that they may well change the lives of all men and women for ever. For we have to ask ourselves, here and now, do we wish to join that procession, or don't we? On what terms shall we join that procession? Above all, where is it leading us, the procession of educated men? The moment is short; it may last five years; ten years, or perhaps only a matter of a few months longer.... But, you will object, you have no time to think; you have your battles to fight, your rent to pay, your bazaars to organize. That excuse shall not serve you, Madam. As you know from your own experience, and there are facts that prove it, the daughters of educated men have always done their thinking from hand to mouth; not under green lamps at study tables in the cloisters of secluded colleges. They have thought while they stirred the pot, while they rocked the cradle. It was thus that they won us the right to our brand-new sixpence. It falls to us now to go on thinking; how are we to spend that sixpence? Think we must. Let us think in offices; in omnibuses; while we are standing in the crowd watching Coronations and Lord Mayor's Shows; let us think . . . in the gallery of the House of Commons; in the Law Courts; let us think at baptisms and marriages and funerals. Let us never cease from thinking—what is this "civilization" in which we find ourselves? What are these ceremonies and why should we take part in them? What are these professions and why should we make money out of them? Where in short is it leading us, the procession of the sons of educated men?

The main purpose of the passage is to

A) emphasize the value of a tradition.
B) stress the urgency of an issue.
C) highlight the severity of social divisions.
D) question the feasibility of an undertaking.

Figure 1: User interface of the web system used to produce visual oscillations, resulting in brainwave oscillations. The user performs a series of SAT reading comprehension questions, which are well-established stressors.

CCS CONCEPTS

• **Human-centered computing → Interaction paradigms**; • **Applied computing → Life and medical sciences**;

KEYWORDS

Mental Health; Brainwave Entrainment

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INTRODUCTION

Recent groundbreaking scientific literature, such as within the field of optogenetics [4, 10], has demonstrated that the brain state can drastically change as a result of exposure to a flickering light stimulus. This phenomenon of natural brain waves synchronizing to the frequencies of external stimuli is called *brainwave entrainment* [5]. However, the applications of this new bioengineering technique have yet to be realized within user interface design.

Computer and mobile displays provide a significant opportunity for non-obtrusive brainwave entrainment, as the therapy can be applied while the user is using the device normally, creating a passive intervention. As a particular use-case of *entraining interfaces*, we focus on interfaces which provide stress relief interventions. However, we note that this work can be expanded to other applications where entrainment has been found to be effective, such as sleep promotion and improving cognitive function (see Background and Related Work).

To date, there is no prior HCI literature attempting to induce brainwave entrainment through external stimuli. Here, we introduce the concept, describe the system development, detail several possible instantiations of entrainment interfaces, and describe user feedback from a preliminary qualitative usability study. As a specific application of the general technique, we explore the use of flickering displays to induce brain changes in the user that subconsciously promote mental health and wellbeing. This work can ultimately result in a translational intervention which can be used in home and work settings.

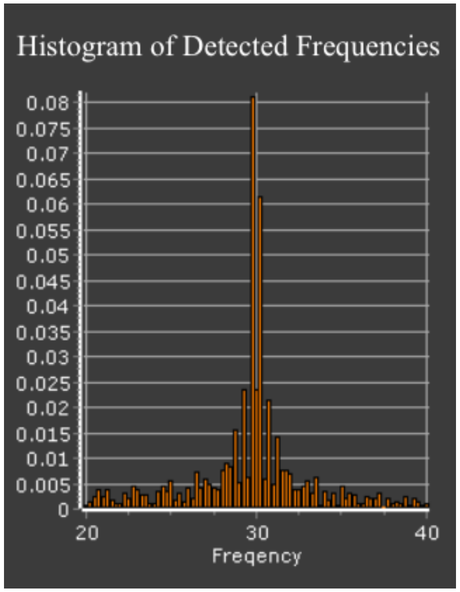

Figure 2: We validated with a colorimeter that the frequencies generated by the website match the expected frequencies. When we enter 30 Hz as the desired frequency, most of the generated frequencies are 30 Hz or right around 30 Hz.

BACKGROUND AND RELATED WORK

Brainwaves

The brain produces neural oscillations at varying frequencies; these are referred to as *brainwaves*. Brainwaves can be detected through an electroencephalogram (EEG). The differing frequencies are associated with different levels of consciousness:

- *Delta waves* (0.1 - 4 Hz) - As the lowest frequency waves produced by the brain, delta waves are present during deep sleep and are associated with the unconscious mind.
- *Theta waves* (4 - 7 Hz) - These waves are present during deep meditation and light sleep.
- *Alpha waves* (7 - 15 Hz) - This is the 'deep relaxation' frequency range, usually produced when the eyes are closed and during daydreaming.
- *Beta waves* (15 - 31 Hz) - This is the most common frequency range, associated with waking consciousness and alertness. However, beta waves have also been associated with anxiety and stress.
- *Gamma waves* (31 - 100 Hz) - Relatively few scientific discoveries have been made about gamma waves, as they are the most recently discovered. Recent research suggests that gamma waves are associated with insight and high-level information processing.

Entrainment

Several scientific studies have demonstrated the usefulness of brainwave entrainment in various application areas and at several brainwave frequencies. Abeln et al. demonstrated that eight weeks of exposure to beats ranging from 2 to 8 Hz (delta and theta) improved the perceived sleep quality and the post-sleep state of athletes [1]. Prolonged exposure to non-invasive 40 Hz (gamma) flickering light has been shown to recruit both neuronal and glial responses to attenuate Alzheimer's-disease-associated pathology [6]. Lakatos et al. have shown that when stimuli are presented in a rhythmic stream, delta oscillations in the visual cortex entrain to the rhythm of the stream, resulting in increased response gain for task-relevant events and decreased reaction times [7]. Cruceanu et al. showed that stimulation with binaural beats and stroboscopic light, synchronized at a 10.2 Hz (alpha) frequency, produced a positive change in cognition. [3]. Given these findings, we aim to create user interfaces which provide external flickering stimuli which result in brainwave entrainment.

SYSTEM DESIGN

Description

In order to explore the effects of oscillatory frequencies embedded in a user interface while the user is performing a stressful task on the interface, we developed a website where the user can take reading comprehension questions from the SAT exam (Fig. 1). The SAT, and standardized tests in general, are well-established sources of stress and anxiety [9]. Sidebar 1 describes some of the implementation decisions involved in creating the oscillations of the background color on the web with respect to precise timing of the oscillations.

We introduced the following parameters into the system:

- the baseline background color, specified as an (R, G, B, A) value, where each color channel can have a whole-number value between 0 and 255
- the oscillatory amplitude per color channel, (A_R, A_G, A_B, A_A), where each color channel can have a whole-number value between 0 and 255
- the oscillatory frequency per color channel, in Hz

Oscillation frequency

The frequency produced by the entrainment interface should match the overall desired frequency of the induced brainwaves in the user. If the interface aims to put the user to sleep, then low frequency delta-band or theta-band waves should be considered. If the interface aims to induce a state of insight, then gamma-band waves would likely produce the optimal effect.

Oscillation amplitude

The amplitude of the wave will affect the user's perception of the oscillations. A smaller amplitude will result in little to no perceived oscillatory behavior by the user, which can result in a subtle unobtrusive intervention but also risks the possibility of no effect at all. The entrainment effect of external visual stimuli which are not consciously perceived by the visual cortex has yet to be explored in the scientific literature, although auditory oscillations have been found to induce an entrainment effect [5]. A higher amplitude, on the other hand, will have an entrainment effect but may result in a prohibitively obtrusive user interface.

Background color selection

The choice of a baseline background color can affect the overall perception and effect of the oscillatory patterns emitted from the interface, possibly inducing a confounding effect. This is because hue has been shown to affect emotional intuition [2] and abstract mappings of concepts [8]. It is therefore essential to choose the baseline background color wisely, or to use a neutral color if attempting to avoid any confounding factors.

Implementation of Oscillating Background Color in Web Programming

There are several possible implementations of oscillation background color hues on the web. The different choices can drastically affect the behavior of the oscillations. Here, we describe two implementations we tried. Ultimately, a platform with minimal delay is desired.

setImmediate(): This method will execute immediately after other browser actions are complete (as 'immediately' as possible). Although not all browsers natively support this method, there are open source implementations that work on all browsers.

window.requestAnimationFrame(): This method tells the browser to run a snippet of JavaScript code before the next browser repaint, which tends to occur at a fixed rate. This allows for queuing of background color change requests and ultimately results in a stable frequency. However, because the repaint requests are queued, the maximum oscillatory frequency is limited. It should be noted that some browsers will attempt to optimize the rendering of the webpage if no repainting is required. If the background color is continuously changed, then this optimization will be avoided.

Sidebar 1: A comparison of implementations of oscillatory background color changes on the web.

SYSTEM MEASUREMENTS

It is important to validate that the system oscillations match the expected frequencies. A different frequency than expected or inconsistent frequencies due to system-level delays may ruin the intervention. Fig. 2 shows the colorimeter measurements of the display at various frequencies ranging from delta to gamma waves. When queuing web frames with *window.requestAnimationFrame()*, consistent frequencies can be achieved up to 35 Hz (but not higher) on the 2018 Macbook Pro used to test the system. This is sufficient for the purposes of an exploratory evaluation of entrainment interfaces, as most of the waves produced by the brain are under 35 Hz.

PRELIMINARY EVALUATION

We recruited N=3 participants for a preliminary evaluation of the obtrusiveness of the flickering displays at varying frequencies. Participants used the system described above (Fig. 1) for each of the 5 brainwave bands (at frequencies of 2 Hz for delta, 6 Hz for theta, 12 Hz for alpha, 22 Hz for beta, and 35 Hz for gamma). In order to test the effect of amplitude for each frequency band at both high and low hue levels, we fluctuated the oscillatory amplitude of the green channel at high hue values (red and blue channels fixed at 255 and green channel fluctuating between N to 255 at decreasing intervals of 1) and low hue values (red and blue channels fixed at 0 and green channel fluctuating between1 to N at increasing values of 1). Participants spent 1 minute performing the typing task in these conditions, unless the display was unbearable, in which case the task was completed and the next task was evaluated. Hue change is measured as the change in the green (R,G,B) color channel on a 2018 Macbook Pro at full screen brightness. All participants were in the same room under identical external lighting conditions. The minimum hue change that participants noticed the flickering while performing the typing task across all conditions is in Table 1, and the minimum hue change where the flickering became distracting is in Table 2.

Table 1: The minimum amplitude (represented as the change in the hue value in the green channel), shown for all 3 participants, for which interface flickering was noticed while performing the reading comprehension exam. At each frequency level, we tried progressively lower troughs (N) for oscillations of high hue values and progressively higher peaks (M) for oscillations of low hue values.

Hue Value	Frequency (Hz)	Minimum Hue Δ
N to 255	2	1, 2, 2
1 to M	2	4, 4, 4
N to 255	6	2, 3, 2
1 to M	6	4, 4, 4
N to 255	12	2, 2, 2
1 to M	12	4, 4, 4
N to 255	22	2, 2, 2
1 to M	22	4, 5, 4
N to 255	35	2, 3, 2
1 to M	35	4, 5, 4

DISCUSSION

User interfaces which utilize brainwave entrainment open the doors for new interfaces which can unobtrusively provide mental health interventions to the user. In this paper, we presented and fleshed out the idea of *entrainment interfaces* and explored a particular simple oscillatory interface which flickers at various frequencies while the user is performing a computerized standardized test. Our preliminary informal evaluation demonstrated that the amplitude of the color oscillations strongly affects the frequency band that is both noticed and tolerated by users. In particular, lower value hues (closer to black) can oscillate at a greater amplitude before the user notices or is distracted by them. However, these results were only gathered from 3 participants, and a more formal user study with several participants is needed.

Table 2: The minimum amplitude (represented as the change in the hue value in the green channel), shown for all 3 participants, for which interface flickering became too distracting while performing the reading comprehension exam. At each frequency level, we tried progressively lower troughs (N) for oscillations of high hue values and progressively higher peaks (M) for oscillations of low hue values.

Hue Value	Frequency (Hz)	Minimum Hue Δ
N to 255	2	3, 2, 4
1 to M	2	6, 5, 5
N to 255	6	2, 3, 2
1 to M	6	7, 8, 7
N to 255	12	2, 3, 3
1 to M	12	5, 4, 5
N to 255	22	3, 4, 4
1 to M	22	7, 6, 7
N to 255	35	3, 4, 4
1 to M	35	7, 9, 10

There are several complexities to performing such research that are important to keep in mind. It is crucial to validate that the frequencies produced by the system match those intended by the user. For example, due to limitations in the precision of system scheduling, the Macbook computer used to run the typing program produced inconsistent frequencies above 35 Hz. A colorimeter or other sensor should be used to validate the generated frequencies.

We also find it important to note that the 'gold standard' of pain and anxiety research is self-reported measurements rather than biometric signals. While biometric markers such as heart rate, blood pressure, breathing, and even brain signals like EEG certainly provide a good quantitative proxy of stress, these are simply bodily responses that are correlated to rather than causative of pain, stress, and anxiety.

FUTURE WORK

There are several possibilities for brainwave entrainment interfaces. As our preliminary evaluation made clear, people have varying thresholds of perception. Therefore, interfaces which adapt their oscillatory frequency or amplitude to the user's perception would be a fruitful area for future work. Other mechanisms of entrainment could also be explored. For example, much of the scientific literature focuses on *audio entrainment*, which we do not explore here. Hybrid interfaces which combine visual and audio entrainment could result in more effective interfaces.

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