Orientation of Attention in Visual Feedbacks during Neurofeedback Relaxation

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Abstract: The assumptions underlying differing approaches to interface design result, in part, on how attention is managed and categorized using theories from media studies. The authors propose the term intraface to refer to biofeedback or other interfaces that are designed to support users who direct their attention inward to inner physiological states. In this paper, the role of representing feedback data in abstract forms is compared in an experiment using Neurosky's neurofeedback device. Although preliminary, the results suggest that mapping biofeedback data from a brain-computer interface (BCI) to highly abstract ambient animations is more effective for relaxation than mapping it to a highly familiar symbolic smiley face icon or to a progress bar. The authors propose that the relative success of the abstract ambient animation can be explained because this representation of biofeedback data is the form that requires the least amount of attention, and that designing biofeedback interfaces that distribute the attention, supports the need of users to the task of directing most of their attention to their inner physiological states.

1 INTRODUCTION

When designing computational systems for Human-Computer Interaction (HCI), the commonly-held assumption is that the interfaces should function as windows between the user and the information (Norman, 1988). More recent work in the area of visualization, such as ambient displays (fig. 1) and what has been turned "informative art" do not, however, share this assumption: they are designed to function in the background of our attention until we attend to them (Bartram and Woodbury, 2011). Once we attend to them, we see more abstract representations of information that provide relatively imprecise information. There is yet another or third approach: some interfaces are intentionally designed to call attention to themselves (fig. 2). The authors of Windows and Mirrors offer a useful way to categorize this diversity: the interfaces that are designed to be invisible function like a "window," while those designed to call attention to themselves function as a sort of "mirror" (Bolter and Gromala, 2005).

In most cases, biofeedback systems need to function as a sort of mirror. Instead of just reflecting the user as a mirror would, however, the biofeedback interface represents the continually changing states of the user. The goal for feedback is to not only provide the user with information about their changing physiological states, but at the same time, is meant to support the user in trying to *affect* those inner states as well. Thus, the information that is being continuously updated and displayed should ideally call as little attention to itself as possible. That is because most of users' attention must focus on trying to sense and change their inner physiological states. Because a user's focus is inward, the authors propose the term "intraface" for these kinds of applications.

2 INTERFACES VS. INTRAFACES

In any biofeedback interface, the user's continually changing inner states are displayed and are attended to by the user, and are designed to help that user learn to change his/her internal state. In this context, the interface must accomplish two seemingly contradictory feats. First, it must provide information for the user and thus must be in the user's attentional zone *to some degree.* Second, *simultaneously,* the user must intentionally focus on

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their inner physiological states. In this case, the intraface must simultaneously function as both a window and a mirror. The study described in section 4 focuses on three different ways of representing biofeedback information, and their effect in supporting a user's ability to focus on his or her inner state. The design challenge for a biofeedback intraface is to reduce the stimulus-driven attentional demands of the feedback so the user can direct as much attention as possible to gaining an awareness of their interoceptive processes.

Figure 1: Ambient information display for WestHouse. This visualization of energy consumption is designed to function as an ambient display – as a backsplash in a kitchen, it remains in the background of our attention until we direct our attention to it. In this case, the greater the energy use, the more attention it draws (Rodgers, 2010).

Figure 2: (*The Wooden Mirror*, 1999, Daniel Rozin). An example of an interface that functions as a "mirror" does so here in a literal way. The wood of this mirror is novel, and is intended to call attention to itself. In addition, a user's image and self-awareness is meant to be a primary part of the information or experience.

In the case of biofeedback, although attention is divided – to the display *and* to inner states – cannot be assumed to be equal or invariable. Informal observations of users during the study suggests that they do one of two things: they continually shift their attention back and forth between the information displayed by the biofeedback device and their changing internal states, or they manage to attend to both the display and their inner state, usually after trial-and-error. During the study, for example, we observed that most users struggled with directing their attention between the display and their inner states; when they attended to the biofeedback display, their stress levels increased. A few users, however, appeared to be able to direct their attention simultaneously to both the display and their inner state. In the latter case, the user appeared to not directly look at the display so much as maintain it in what can be described as a more distracted or ambient way.

Ideally, in biofeedback contexts, because attention is necessarily split, the interface should function more like a partially transparent mirror. Because the task is to learn how to change one's inner state, much of a user's attention needs to be directed to this task, especially when it is a task that the user has not attempted before. At the same time, however, feedback is intended to support the task. That feedback should take a secondary role, and should therefore be designed so that it requires as little attention as possible. In a pre-test trial, one user, for example, suggested that her split attention worked in a figure/ground relationship; that is, s/he was able to put the displayed information into her attentional background. It may be possible that users who are experienced meditators may bring this skill, and that is a factor we will determine in future work.

Biofeedback is a task that is unfamiliar for most users. Indeed, physiological research suggests that we generally do not pay attention to our inner states. According to Hermann Helmholtz, we have 100,000 times more information about our inner or interoceptive states than information about our five senses or exteroceptive sense (Helmholtz, 1995). Yet, if we attended to the sheer quantity of this information, we would have little capacity left to focus on our senses and on our immediate environment (Leder, 1990). Thus, information that our bodies generate about our internal state normally functions in the background of our conscious awareness and attention. When threatened, however, – say, by eating bad oysters – we are able to attend to at least some of this information. Indeed, depending on the threat, this information can capture nearly all of our attention and impel us to take action. Such action is, in some instances, involuntary – the information provokes involuntary processes that take over the control we usually have over, in this case, our ability to hold food within.

For contexts such as biofeedback or meditation, users must overcome this propensity to ignore their inner states, and must learn to effect change by processes that seem elusive. While it is easy to exert conscious control over processes such as breathing, it is more difficult to exert control and effect change over other processes such as heart rate, brain waves, and Galvanic Skin Response (GSR). Nevertheless, this is an ability that can be learned, and through practice be made easier to do; in some cases, a long-term practice can become a habit. Stress reduction learned via biofeedback is a common example.

To differentiate the ways in which interfaces serve to direct attention, we propose the term intraface for technical systems that are designed to focus a user's attention inward, to their interoceptive states.

2.1 Biofeedback and Brain-Computer Interface

Biofeedback technology is typically used to gain an awareness of physiological processes; the goal is to learn how to manipulate processes that can be controlled, such as brainwaves, muscle tone, skin conductance, and heart rate. Biofeedback sensors attached to the user's body capture on-going data on each process. This data is then sent to a computer or other device where it is then mapped to visuals or sounds and displayed (Schwartz, 1987; Montgomery, 2008; Andreassi, 2007). The representation of this data provides the user with continually updated information about the activity of these processes, often in near real-time.

Often, the physiological changes occur in conjunction with changes in thoughts or emotional states. With practice, these changes may be maintained without the use of the biofeedback technology itself. One of the major principles of this approach is that the user gains the skill to control aspects that otherwise primarily operate unconsciously (Frank et al., 2010). Biofeedback regulation techniques have proven to be effective in treating disorders such as attention deficit hyperactivity disorder (ADHD), anxiety, chronic pain, epilepsy and a host of other conditions (Monastra et al., 2005; Rice et al., 1993; Sterman, 2000).

One of the well-known ways that biofeedback is used is to enable patients suffering from neurological disorders to observe and regulate their neural oscillations towards a healthier direction; this is termed neurofeedback. In this practice, patients are usually monitored using a non-invasive brain activity recording method such as EEG. Patients obtain an awareness of their brain performance through forms of feedback, usually while performing a certain task.

Interacting with software systems using these so-called brain-triggered commands has led to a research area known as BCI. Users of these systems control and drive functions embedded in software by commands issued by the brain – brain activities are picked up using a signal acquisition approach and then translated into actions using signal processing and machine learning methods. This technology was initially developed to enable patients with severe motor injuries to regain mobility (Wolpaw et al., 2002). For instance, amyotrophic lateral sclerosis (ALS) patients who gradually lose the ability to control their muscles can use commands originating from their brain to control a robotic arm or to operate a wheelchair via brain activity (Sellers and Donchin, 2006). Other applications of BCI include gaming and virtual reality (Bayliss and Ballard, 2000). Creating such systems that can utilize brain activity as the communication and control medium enables health practitioners to develop treatments for patients.

2.2 Examples of Intrafaces

Interfaces designed for biofeedback systems can all be termed intrafaces because they are intended to support the user's task of learning how to change their inner or interoceptive states. The primary goal is for the user to direct his or her attention inward. Because this task is generally novel and relatively difficult, most of a user's attention should ideally remain directed inward. Thus, the design of the interface to the feedback information should require as little attention as possible. Early biofeedback devices displayed a graph, a wave, or a sonic tone. More contemporary biofeedback devices offer a number of ways in which the information can be represented: by numbers, graphs, smiley faces or more abstract images.

VR researchers have explored displaying biofeedback in an immersive virtual environment. Designers of the Virtual Meditative Walk (Shaw et al., 2007), for example, created a VR system that incorporates biofeedback in order to for the user to gain an immersive sense of when and how they may affect their stress levels. Rather than displaying biofeedback information in familiar ways, they mapped the continually changing biofeedback data to fog that dissipates as users lower their GSR data. Because the fog surrounds a user and lacks any specific point to focus on, these researchers suggest that it is very different from VR systems designed to distract a user from their pain (Shaw et al., 2007). In VR pain distraction, the virtual environment (VE) is designed to capture and hold as much of a user's attentional capacity as possible (Hoffman, 2000). In the *Virtual Meditative Walk,* in contrast, the fog demands attention (Shaw et al., 2007) and in this sense functions more like an ambient display.

Other studies that compare the difference between a VE that is realistic to a VE that is abstract have been proposed. The study below is the first stage of this planned work.

3 THE STUDY: THE ROLE OF ABSTRACTION IN FOCUSING ATTENTION INWARD

In order to assess if in fact users are better able to focus on their interoceptive states if the biofeedback data is represented as abstractions, we designed the following study. We used a BCI that monitors meditation status originating from the brain during relaxation and maps brain activities to a visual representation as feedback. 12 participants were exposed to three types of feedback and 4 people were monitored without being exposed to any feedback as control group. They used different representations of biofeedback data, including an ambient one to control their relaxation state.

4 METHODOLOGY

4.1 Apparatus

We used MindWave Mobile from NeuroSky Inc. to acquire neural brain activity associated with relaxation state. The device is designed for practical applications of BCI; it consists of a dry electrode that picks up EEG signals and transmits data to the receiving end via Bluetooth technology (fig. 3).

4.2 Participants

Participants were a convenience sample comprised of 16 male and female university students between the ages of 21 and 26 (M = 23, SD = 3.49) with no previous meditation or biofeedback experience. They were recruited using Doodle event manager. Participants were briefed about the experiment via email before arrival, and signed a consent form before the experiment.

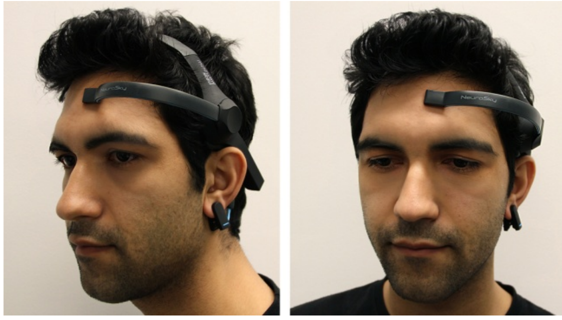

Figure 3: MindWave Mobile (side and front view).

4.3 Experimental Design

To assess different types of visual feedback in a brain-triggered system, we designed a between-subject experiment. The independent variable was the type of feedback or control group that the participants were randomly exposed to and the dependent variable was the level of relaxation in a percentage reported by NeuroSky's Mindwave Mobile. We developed three visual types of feedbacks using processing programming language consisted of the following: a progress bar, an animation of cartoon face, and a slow moving abstract animation.

4.3.1 Control Group

In this group, participants were instructed to relax by deep breathing and to try to keep their mind free of distractions. They were not exposed to any visual feedback during the relaxation process.

4.3.2 Progress Bar

Participants of this group were instructed to look at a progress bar which shows how relaxed a participant was during relaxation (fig. 4). The more relaxed the participant was, the more filled the progress bar was; a fully filled progress bar indicated the most relaxed state (out of one hundred, from 0 to 100).

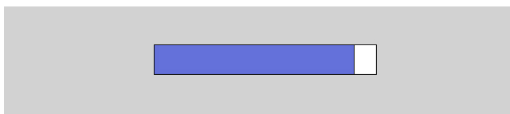

Figure 4: The amount the bar is filled directly correlates with the participant's relaxation state; an empty bar represents a state of agitation, and a fully filled bar represents the most relaxed state.

4.3.3 Smiley Face Animation

In this group, the percentage of relaxation affected the animation of a cartoon-like smiley face. When the participant was less relaxed, the face looked sad, darker, and gray. As the participant reached a more relaxed state, the face became happy, lighter and more colorful (fig. 5).

Figure 5: The image gradually transitions between these three images.

4.3.4 Ambient Feedback

The relaxation level in this group was mapped to a video that changed color with respect to participant's relaxation status. The original video constituted abstract animations and was meant to be the main focus of participant's attention (fig. 6). As the participants moved from a non-relaxed state to a relaxed state, the colors of the video changed from red to orange to green to blue, respectively. The goal in this mode was to display the feedback in a passive, implicit yet informative manner.

4.4 Procedure

We randomly assigned each participant to a feedback type and recorded relaxation levels in percentage for 5 minutes. The sampling rate provided by NeuroSky MindWave is one data point per second; hence there were 300 data points for each participant at the end of the trial. This was saved as plain text file for further analysis. NeuroSky MindWave conveys the patient's relaxed mental state with percentages utilizing a proprietary algorithm called eSense. According to NeuroSky, eSense constitutes artifact rejection and machine learning methods that can distinguish among higher cognitive mental states such as meditation and attention. The manufacturer of MindWave conducted an extensive study to distinguish when participants are in a calm and relaxing state by providing relaxation levels with percentages ("NeuroSky's eSense Meters and Detection of Mental State," 2013). This output as opposed to conventional raw EEG that requires preprocessing along with machine learning techniques to classify mental states is used for practical application-oriented studies.

4.5 Statistical Analysis

We initially averaged 300 data points for each participant into a single value representing the relaxation level. To test for potential significant difference among means of relaxation levels, we ran a one-way analysis of variance (ANOVA) test. To further investigate the effects of each feedback, we ran a pair-wise Tukey HSD test in order to compare all pair of feedback types.

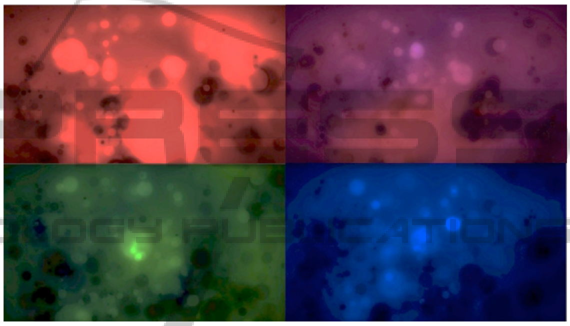

Figure 6: The top left image (red) represents agitation. As the user relaxes, the image transitions to the bottom right image (blue), which represents the most relaxed state. This slow-moving animation does not offer any one area that demands more attention than any other area.

5 RESULTS

Primary observations of data are demonstrated in Figure 7. The results suggest that the participants who are exposed to ambient feedback have the highest level of relaxation compared to the other visual feedback scenarios and the control group (Mean= 77.61%). The Face Smiley mapping (Mean=68.89), Progress Bar (Mean =58.68), and the control group (Mean=46.78) are rated afterwards, respectively.

The results of one-way ANOVA suggests that there was a significant effect of independent variable feedback type on dependent variable relaxation level for 4 conditions $F(3,12)=23.74$, $p<0.0001$ at the p value <0.05. Figure 8 demonstrates the results of analysis for all the conditions.

The results of pair wise Tukey HSD test suggest a significant difference between ambient feedbacks when compared to other feedback types. Table 1 provides result of Tukey test along with statistical

Table 1: Comparing feedback types pair-wise using Tukey HSD.

Feedback type 1	Feedback type 2	p-Value
Ambient	Control group	<.0001
Ambient	Progress bar	0.0013
Ambient	Face	0.0139
Face	Control group	0.0029
Face	Progress bar	0.5205
Progress bar	Control group	0.0329

significant at p value <0.05. It also supports the fact that the difference between progress bar mapping and the face mapping is not statically significant.

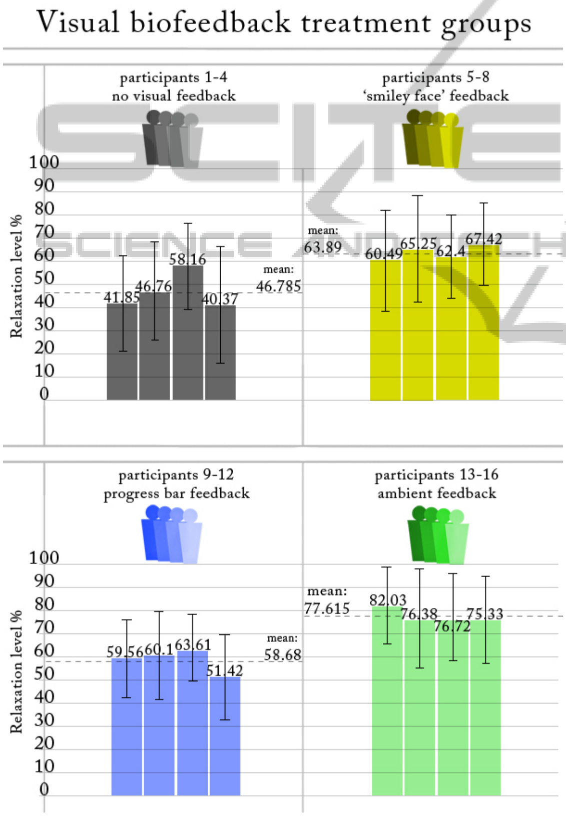

Figure 7: average relaxation level for each participant along with its standard deviation. The average relaxation level for each feedback condition is also represented.

6 DISCUSSION

The results clearly show that subjects achieve a higher level of relaxation when they use the ambient video display compared to the other conditions. The cartoon face and the progress bar are equivalent (p=0.52 no significant difference). The control group (relaxing without feedback) resulted in the lowest

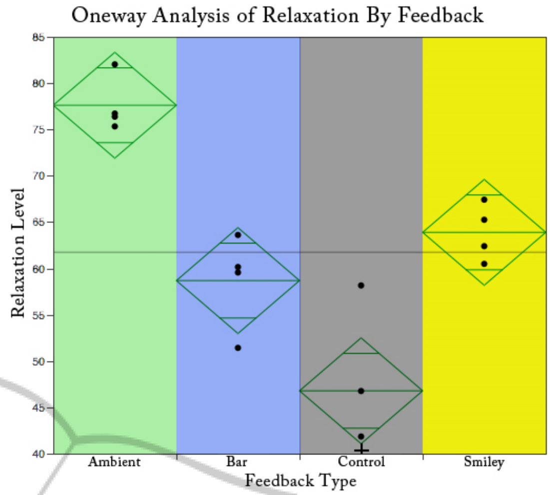

Figure 8: Visualization of data points for different participants in all conditions.

relaxation readings.

Our suggestion as to why this is the case has to do with the role that visual attention plays in each of the treatments. In the face condition, the visual stimulus can be strongly attended to, namely the curve of the mouth and the color of the face.

Moreover, the smiley face is a schematic face, and is thus a highly familiar symbolic cue. Cues like these are often referred to as a gaze cue: they appear to be processed faster and more accurately, and are thought to be so very well-learned – or even overlearned – that responses to them may seem reflexive, but are automatic (Vecera & Rizzo, 2006). If this is true, and if gaze cues are more related to goal-directed attention than stimulus-directed attention, why then, does the ambient video function better in supporting users' attention to their interoceptive processes? First, unlike direct cues, gaze cues persist longer, and do not produce do not produce inhibition of return (Friesen & Kingstone ,1998). Second, the human face is the most important social stimulus we process (Itier et al., 2007), and is fundamental to social cognition. Thus, schematic faces actually function to direct attention, or by "popping out," call attention to themselves. Although schematic faces are thought to support task-oriented attention (Wright & Ward, 2008), the biofeedback task may be qualitatively so different from those used in attention studies that they function as a unique case. Put another way, when the task is to try to focus one's attention inward, toward one's interoceptive senses, recognition of a face, no matter how schematized, implies that that we are impelled to look back at its highly salient visual features. In this case, the schematic face functions more like a stimulus that cannot be easily ignored. In addition, that it is a face means that it bears visual features perceived as a facial feature, one that users can attend to in a focused manner.

Similarly, the progress bar has a single visual feature – the bar location. In addition, some users in terms of a performance can interpret the progress bar as a goal or challenge. That is, the half empty progress bar can be perceived as a challenge to fill, and that challenge seems to continually draw attention outward, to the bar.

By contrast, the ambient video distributes visual attention across a wider range of the visual field. In addition, the video has no specific element to focus on. Also, the video changes slowly and continuously, frame-to-frame. Slow changes are difficult to attend to, particularly when the changes are taking place in visual stimuli that do not contain a clearly identifiable central object of interest (Auvray et al., 2003).

Thus, in the ambient video condition, attentional resources that could be devoted outward to highly salient visual features can be instead directed inward towards managing the internal sense of relaxation, with occasional reference to the color and general appearance of the ambient video.

The NeuroSky EEG sensing device generates the numerical measures of relaxation. The relaxation measure was generated at NeuroSky's labs by having a number of subjects enter a relaxed state and recording a sequence of raw sensor readings during this state. A neural net recognizer was trained on this set of subject data, and the output of this trained neural net is the relaxation reading.

The advantage of this is that we did not have to train our own machine learning system to recognize raw readings as "relaxed" or otherwise. However, the disadvantage of using NeuroSky's recognizer is that we have to trust that the NeuroSky device measures what it claims to measure. Thus, we plan in future work to compare NeuroSky's measures with data from other biofeedback devices.

We observed that subjects almost always attended to the progress bar and smiley faces, but not the ambient animation. For reasons that are unclear, subjects tended to look at the animation, close their eyes, and look back at the animation from time to time, ostensibly for updates from the feedback. It is unclear whether this resulted from the kind of representation: the progress bar and smiley face may have appeared to users to be more "formal," while the animation may have been perceived to be more informal, especially because no one-to-one data mapping appeared evident.

7 CONCLUSIONS

Differing approaches to interface design operate on underlying assumptions of how attention is directed and managed. We draw upon a theory from media studies that characterize these approaches as transparent windows onto the information displayed, or mirrors that demand that users pay attention to the interface itself, and in some cases, include reflections of users themselves in the interface. Interfaces for contexts that support users is usually an unfamiliar task of directing their attention inward, to their physiological processes, like biofeedback should call as little attention to themselves as possible. This enables users to maintain focus on their inner states, and on their ability to learn how to change them. Biofeedback presents a challenge in that the feedback tends to split attention to the representation of the feedback and to users' inner states. The authors propose the term intraface to refer to biofeedback or other interfaces that are designed to support users who direct their attention to inner physiological states. The role of representing feedback data in abstract forms is compared in an experiment using Neurosky's neurofeedback device. Preliminary results suggest that mapping biofeedback data from a brain-computer interface (BCI) to highly abstract ambient animations is more effective than mapping it to a highly familiar symbolic smiley face icon or to a progress bar. The relative success of the abstract ambient animation over the schematic face or progress bar may be because ambient representation of biofeedback data requires the least amount of attention. Therefore, designing biofeedback interfaces should be designed so that they require the least amount of attention, supporting the need of users to the task of directing most of their attention to their inner physiological states.

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