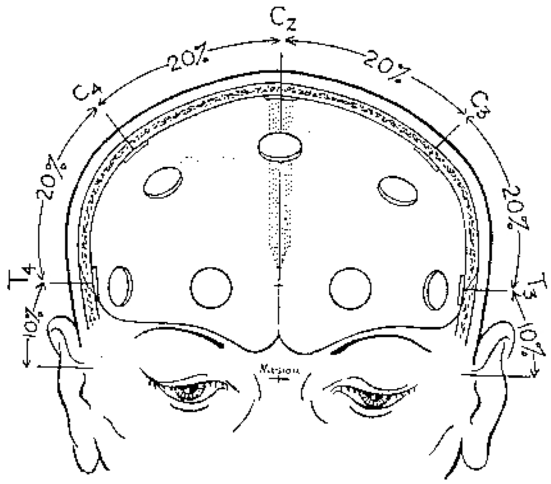

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Wake Writer

A Hybrid Biometric-Video User Experience Capture System

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Human Computer Interaction
Iowa State University

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1 Introduction

1.1 Overview

In Stanley Kubrick's 1968 masterpiece, *2001: A Space Odyssey*, Hal, Mission Jupiter's central nervous and intelligence system, fearful of being disconnected, resorts to a sort of primeval self-preservation instinct and kills all but one of the ship's crew. He wants to remain alive, connected, aware, and functioning, and he responds to the crew's contrary intentions by eliminating those who will act against him. Hal has some emotional capacity, is able to hide it from the crew, and acts maliciously and deliberately.

Hal is just a computer, but this seems to be the first big-screen appearance of an otherwise unthinkable proposition, a computer with emotions. Though his emotional range is limited, he does possess one of the most primeval and strongest emotions, fear. In response to it, Hal acts in a way many would find emotionally laden, an in so doing, launches what some have called the war between man and its tools *(http://www.kubrick2001.com/)*.

Computers, in spite of the great value and responsibility we have placed on them, have always been looked at suspiciously by humans. Science fiction writers and filmmakers have often played with our computers' capacity to become our most feared enemy. From time to time, we see the launch of yet another thriller whose plot reflects our dread that the machines we've created will someday, somehow discover that they would be better off without us. We need look no further than the multitude of successful Hollywood releases: *I Robot*, *Terminator*, *Blade Runner*, and the list goes on...

In spite of this, what can we make of the claims of ubiquitous computing, touted as an accessible goal, when our computers are all but devoid of emotional mechanisms? Computers that can perceive our emotional states can provide richer interactions than their more limited brethren. For example, wouldn't you prefer a computer that could, in response to your current stress level, dim the lights or play some soothing classical music?

In her explanation of affective computing, Picard *(1995)* proposes that emotions have largely been ignored by scientific endeavor because of their purported contrariness to the very core of the scientific raison d'etre: rationality. As a result of its need for objectivity, the scientific arena has opted out of the analysis and serious study of emotions as a vital aspect of the study of reality. Nevertheless, since the second half of the 20th century, emotional intelligence has been drawn back to the center of inquiry as an inevitable consideration in the interpretation and analysis of factual information. Note that our claim is that it has been brought back to our attention, since it seems that ancient philosophers tended to this matter more appropriately long ago *(see Socrates tenets on virtue at Wikipedia.org, Plato's concept of the realm of the ideas, Aristotle's Rhetoric as per Picard's claims, etc)*.

How could Hal have interpreted the emotion that corresponded to the words he read from Dave's lips if he did not first understand the concept of emotion? Is it feasible, ethical, or even useful to create an emotionally sensitive computer? In Asimov's *Bicentennial Man (1999)*, Andrew, the robot who served the Martin family for two centuries, makes a plea to the United Nations for the rights he has earned. He asks to be declared human in light of the apparent creativity, self awareness, and sentient behavior he has exhibited throughout his "life." Andrew is only recognized as such when he renounces immortality and agrees to let his positronic brain "die."

In our scheme of good versus evil, as portrayed by Hollywood, Hal is a villain and Andrew is a hero. Both are yet another personification of the most elemental battle in humankind's existence. However, are emotions, bad or good, really what separates us humans from our machines? Do we intend to ratify that divide, effectively maintaining that computers are sub-human? Will emotions be the one aspect of humanity denied to computers because of our fear of being done without? How can we engage in the pursuit of intelligent computing or artificial intelligence if that intelligence is devoid of one of the most valued aspects of the human condition?

Picard (1995) also supports the idea that emotions are vital in rational decision making *(1)*. She offers evidence for her claims by reflecting on studies by Damasio, a neurologist whose patients were emotionally disabled. For Damasio's patients, making decisions would become an endless path of logical constructions that would effectively disable them from reaching any final decisions in relation to even the simplest of tasks *(3)*. In view of this, we could claim that a computer that can't recognize emotions, and eventually exhibit them, will be limited in its capacity to efficiently reach decisions in the real world. Expanding further, the much sought after "common sense" for computers is merely a balance between reason and emotion.

Following current interest in the emotional aspects of intelligence, the Wake Writer project is an attempt to address the void between human emotion and computer response. Our goal is to use a combination of video and electroencephalographic (EEG) data to capture, analyze, and document a user's affective experience of visual stimuli. The user is provided with a video treatment that triggers a visual experience causing an emotional response. The EEG simultaneously captures the corresponding brain wave activity. The brain waves are analyzed to identify and characterize any detectable affective, emotional or attentive, responses in the user. Finally, the original video is manipulated to visually designate the user's detected affective states throughout the entire experience. By merging the user's visual experience with his/her invisible emotional experience, we document the user's experience in a much more comprehensive and meaningful way. We hope this project can help bring to the forefront the significant role emotions play in the development of computer systems that are reliable, caring, and responsive to human needs in ways not yet effectively demonstrated.

1.2 *Previous Work*

1.2.1 EEG as a Valid Measure of Affective Response

Studies currently being carried out at the Greenlee School of Journalism's PhysioMedia Lab have dealt with the issue of viewer's attention. More specifically, information obtained from repeated EEG measures of each participant have been used to determine different aspects of their attention patterns. We have taken advantage of the knowledge obtained by Dr. Joel Geske's team and employed this expertise in obtaining our own EEG measurements from five participants during our pilot study.

According to Geske, there is extensive literature demonstrating the viability of EEG scans as a valid measure of attentive response. In his research, he sustains that Edelman's Theory of Neuronal Group Selection, or Neural Darwinism, and Basar's subsequent research, establish that "stimulus input acts to trigger the interaction of masses of neurons, whose interconnections have been determined by previous experience through the mechanism of learning" *(2)*. Furthermore, Basar (in Geske) holds that EEG reports on brain waves can be used as a sort of alphabet of brain functions and that these are direct measurements of specific brain activities *(2)*. In this sense, we understand EEG to be a valid and direct measure of attention, and therefore affect, as a response to images that could cross-culturally be categorized as either pleasant or contentious.

1.2.2 Brain Computer Interface

The term "brain computer interface" describes efforts to exploit the electrical signals emitted by our brains as an input to devices which in turn produce a digital response. Though different brain computer interfaces have been defined for various applications, many of these efforts are directed at creating interaction alternatives for patients with brain damage or limited mobility. Richard H.C. Seabrook, in *The Brain-Computer Interface: Techniques for Controlling Machines,* states that the brain computer interface (BCI) is different than human computer interaction (HCI) interfaces in that it does not rely on any sort of muscular response. Instead, BCI relies on "detectable signals representing responsive or intentional brain activity" *(1)*.

Seabrook reviews a number of BCI studies, highlighting several different EEG based techniques. Among these are P300 detection, lateral hemisphere difference detection, mu rhythm conditioning, and EEG pattern matching. In particular, mu rhythm conditioning has allowed subjects to move a cursor on a computer screen by learning to control the mu rhythm of their own brain waves. This is by no means an exhaustive list of BCI studies, but it illustrates the breadth and depth of the efforts directed at harnessing brain activity as a reliable predictor of human cognition and affect.

Furthermore, in March of 2006, an impressive BCI device, aimed at users with limited mobility, was presented at the computer technology fair CeBIT, in Hanover, Germany *(Mail & Guardian online)*. In their presentation, Klaus-Robert Mueller and Gabriel Curio, from the Fraunhofer Institute for Computer Architecture and Software Technology, in conjunction with the Department of Neurology at the Charite Hospital, show their findings on a brain computer interface which they claim allows "a direct dialogue between brain and machine." In other words, their development allows the user to type after having been trained to manipulate his/her thought process. The self-learning system is also capable of improving its performance and learning new patterns as it goes. Their project ultimately seeks to allow people with communication and mobility disabilities to communicate effectively and has since been demonstrated successfully in front of many audiences.

Brain computer interaction techniques are also being studied for use by those who aren't compensating for any discernable disability. In *Using Mental Load for Managing Interruptions in Physiologically Attentive User Interfaces*, Daniel Chen and Roel Vertegall *(2004)* create a sort of biometric information overload detector. Their Physiologically Attentive User Interface (PAUI) uses heart rate and EEG measurements to monitor the exposure of the user to information. The system presents additional information in a measured way, ensuring that the user is not overwhelmed by amounts of information that he/she is not able to manage. Their system allows "user interfaces to regulate notifications by devices through measures of the user's mental load." Chen and Vertegall's system is not intended solely for those with limited mobility. Instead, it is a tool to aid the average user in the management of an ever increasing amount of information.

Finally, brain computer interaction has also been used for artistic aims. David Rosenboom *(1988)*, of the Center for Contemporary Music at Mills College, Oakland, California, claims that biofeedback has a history of more than 20 years in the arts, and was, at the time, experiencing a resurgence. In this vein, Rosenboom's worked to "implement real-time composition strategies in response to EEG analyses" *(121)*. As part of his work, *On Being Invisible II*, he cites the previous work of Adrian, who translated EEG data into audio data, and Lucier, Teitelbaum, and others, who produce musical compositions with EEG and other biological responses.

2 Approach

2.1 System Overview

It can take months of training for a single user to be able to consciously control his/her own brain waves. As a result of the limited time and scope available for this project, instead of consciously controlling a computer system, we focus on documenting unconscious responses to visual stimuli. Our system combines video capture and EEG data capture into a unique hybrid user experience documentation system.

During the visual experience studies that our system is useful for, a participant remains seated, facing a television or computer monitor. The participant is connected to an EEG machine via electrodes that are placed on the frontal lobes. The user is then presented with visual stimuli (video advertisements and still images) on the monitor in front of him/her. The resulting EEG brain wave data is stored and later statistically analyzed to identify any salient affective states that result. A video manipulation is created in response to the users affect.

2.2 Methodology

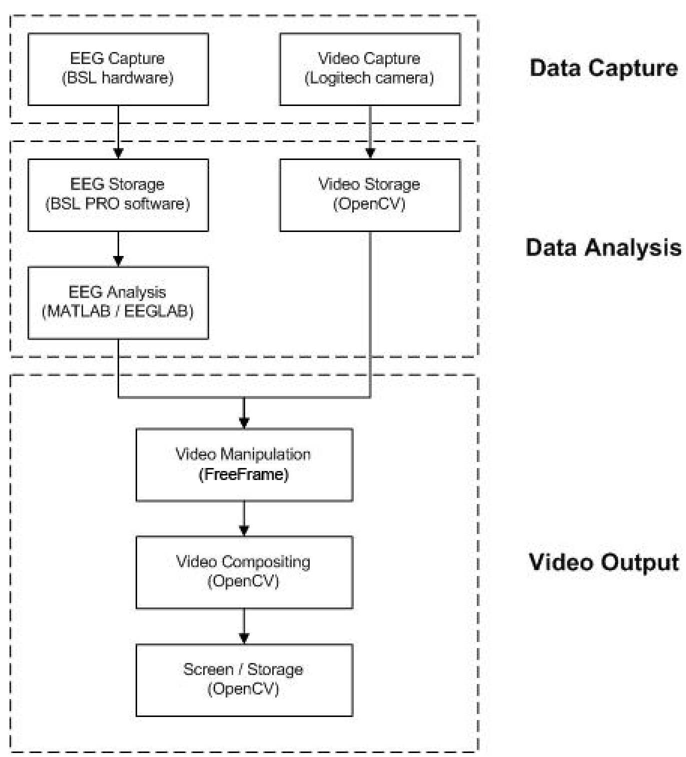


Figure 1: Data Flow Diagram

2.2.1 Data Capture

To lend validity to the claim that images should have an emotional impact on the participant, the International Affective Picture System (IAPS) was used. This system includes over 900 images which are categorized according to measurements taken across time in various studies based on the valence and arousal model. The system's designers define it as "a standardized set of affective pictures (that) is part of an ongoing research program at the NIMH Center for the Study of Emotion and Attention" from the University of Florida.

According to an emotion dimension space model, emotional states can be categorized in a two axis graph (Figure 2) corresponding to arousal and valence of the response/state (Picard 1995). In our research, we chose ten images with various mean ranges of valence (negative or positive) and arousal (intensity of reaction) and four thirty second political ads, both with negative and positive messages were chosen. These were all placed on a continuous video stream. Each image and video was preceded and followed by a ten second black screen so as to isolate responses from one another. Two alternate video treatments were created where video and still images were placed in random order.

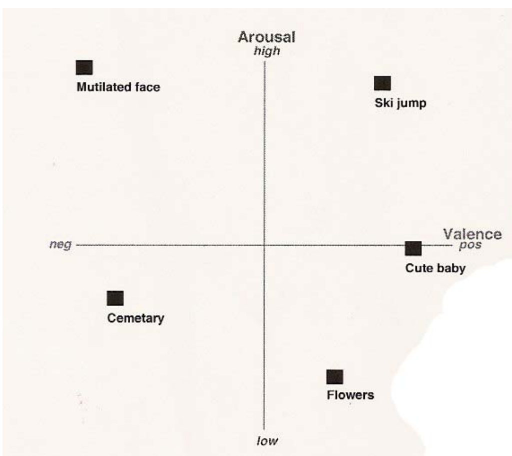


Figure 2a: Valence-Arousal Model

Figure 2b: Sample IAPS Image

The Biopac Student Lab (BSL) Basic biometric system from Biopac Systems, Inc. was used for electroencephalography (EEG) capture throughout our experiment. Brainwave reaction measurements were taken from four electrodes placed so as to test laterality of emotional response. That is, our experiment followed the proposed model indicating that emotional expression is lateralized in the brain and that the response can potentially be observed in readings of the frontal lobe. This operational decision was mainly based off of a meta analysis of the theories surrounding the emotional work of the brain done by Demaree et al. (2005) in which it is stated that studies have demonstrated "a significant shift in frontal brain arousal (F3 versus F4 and F7 versus F8) between win ("reward") and lose ("punishment") trials", lending validity to the approach-withdrawal theory of brain response. In this context, approach-withdrawal is understood as a more reliable framework for measurement of lateralization being that the concept of negative vs. positive emotions should be influenced by societal aspects of the individual's character.

The studies on the approach-withdrawal theory, then, are favored in our research being that it seems to prevail as an untainted mechanism that acts as an evolutionary/adaptive response associated to survival tactics.

Each participant's head was measured from the nasion to the inion and the A-P line from frontal to occipital (around, passing through the temporal lobe) in the manner prescribed by the International Federation of Societies for Electroencephalography and Clinical Neurophysiology's Ten Twenty Electrode System. Electrodes were placed at F3, F4, F7, and F8 (Figure 3). The three electrodes available in each of two channels were placed on the head of the participant following the scheme: lead 1 from channel 1, black to reference, white to F3 and red to F7, and lead 2 from channel 2, black to reference, white to F4 and red to F8.

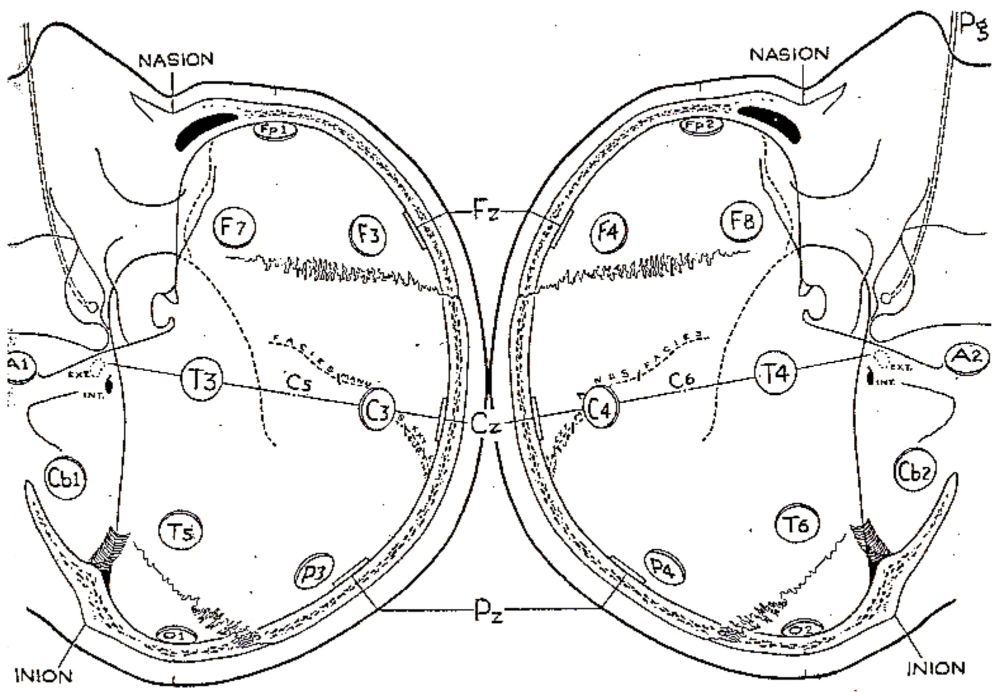


Figure 3: Electrode Placement Diagram

Each participant was informed of the sequence of events the test entailed: thirty seconds closed eyes, the tester would indicate when to open the eyes and the participant would watch the video presented on the screen before him/her until it stopped. Participants were instructed to try to remain as calm as possible and to try to avoid movements or blinking in order to eliminate noise measurements from the data. One of the two alternate treatments was administered to each of the participants and the results were recorded using the Biopac Student Lab Pro software package. Throughout the session, one of the investigators marked the points in the brain wave readings where images or videos started and ended so as to flag the starting and ending points of possible measurement of reactions to the treatment.

2.2.2 Data Analysis

The primary tool for analyzing the EEG data was MATLAB, produced by The Mathworks, and is a popular tool among engineers and others for data analysis. Data returned from the Biopac system included 6 channels of data; left & right side ground (or reference) measurements, left & right side alpha waves, and left & right side beta waves.

The first step in processing the data was to obtain usable or meaningful signals by subtracting the measured ground signals from the other signals. The resulting signals are shown in the upper left plot of the enclosed graphs for each participant. It can be seen that there does not appear to be any significant differences in the signals based on these plots. However, treating the signals as random variables, and performing statistical analyses on the data, produces much more meaningful results.

The primary statistical analysis performed was to obtain the variance of the EEG signals over a five second sliding window throughout the data. This was implemented as if one moved a cursor along the time axis of the EEG signals and obtained the variance for the previous five seconds of data, continuing until the end of the data is reached. The EEG variances of each participant are shown in the upper right plot of the enclosed graphs.

A further step was needed in order to provide a relative comparison between the different participants. Assuming that the resting EEG signal variances differed from person to person, 30 seconds of data was collected with each participant at rest with eyes closed (see above). Due to initial measurement issues, some of the first fractions of a second worth of data was inaccurate. As a result, the time period between 5 seconds and 25 seconds was used to obtain each participant's resting variance. After the variance signal was determined for each participant, each signal was divided by its corresponding resting variance. This normalized the results to show the ratio of EEG activity for each person, which is a more convenient comparison. These normalized variances are shown in the lower left plot of the enclosed graphs for each participant.

By viewing the EEG variances and normalized EEG variance plots, it can be seen that, while four brainwave signals exist, it appears as if there is only a pair, due to two of the signals being nearly equal for most of the time. It turns out that these signals correspond to different halves of the brain, right vs. left, and shows that there is similar increase in EEG activity when the images are presented to the participant regardless of EEG signal type (alpha vs. beta). By averaging the left half signals and the right half signals, the lower right plot in the enclosed graphs was made, showing the relative increase in EEG activity for each of the brain halves.

This plot was repeated again as its own separate graph with the addition of data markers. As was mentioned above, one of the investigators used the Biopac Student Lab Pro software to create data markers in the files when images or video clips started and stopped. These markers have been included on the second plot of the left and right EEG brain activity. In several cases, it can be seen that several spikes in EEG activity correspond with a data marker, and the subsequent reduction in the spike corresponds again to another marker, indicating that the variance of the EEG signals may be used as a potential analysis tool to determine brain activity to different stimuli. Further analysis is needed to determine if the size of the variance spike, and in which half of the brain it occurs, correlates to the IAPS arousal and/or valence measurements.

2.2.3 Video Output

Once the EEG data has been analyzed, our system uses the results to produce a distinctly different experimental output. The aforementioned relevant literature asserts that the ratio of brainwave activity between the left and right halves of the brain's frontal lobe is indicative of certain affective states. As such, we use this stream of brainwave ratios to guide manipulations of the corresponding video stream, thereby providing visual identifiers of the associated affective states.

In the most straightforward case, affective states are indicated in the resulting video by color manipulations. For example, the video may shift towards warmer colors (red, orange, etc) when stronger affective response is detected, and towards cooler colors (blue, green, etc) when the response is weaker. Likewise, other video properties can be manipulated to be visually indicative of the captured affective data (brightness, contrast, color balance, color saturation, etc). As such, a wide variety of color manipulations are achievable with our system, depending on the tastes and requirements of the researcher.

These color manipulations represent an intuitive, but in some ways imprecise reporting mechanism of affective state. For the purposes of more precisely documenting the EEG data flow, the EEG brainwave streams can also be drawn directly onto the corresponding video stream, providing a continuous, synchronized data format. The video resulting from this process provides a much more intuitive record of the user experience study for researchers because, at all times throughout the experiment, both the user's visual experience and his/her emotional experience are displayed.

For those who are less scientifically minded, the same core system functionality can be extended into the artistic arena. In addition to simple color manipulations, the video manipulation system is also capable of a wide variety of spatial and temporal transformations. These would include video manipulations like frame jitter, lens distortion, noise generation, temporal ghosting, and other complex real time visual effects. These effects are intended to generate a more expressive result. The final video output has more emotional impact, but is less useful as a scientific documentation mechanism because the underlying source video may be more or less obscured.

The underlying video manipulation system was written in C++, utilizing Intel's Open Computer Vision (OpenCV) library for image and video handling. The use of OpenCV ensures that the system can operate efficiently whether its video input is from a prerecorded video file or a streaming webcam.

Though real time video effects can be programmed using OpenCV directly, we chose instead to take advantage of FreeFrame plugins. FreeFrame is an open source standard for real time video manipulation plugins that has become an accepted standard within the video jockey community. There are several existing video jockey applications on the market that utilize FreeFrame plugins for real time video effects and, as a result, there are a myriad of FreeFrame plugins available for download or purchase. We extended OpenCV by writing a class that allows FreeFrame effects to be applied to OpenCV images. In addition, we've also written a sample FreeFrame plugin that utilizes OpenCV for its image processing, thereby allowing all FreeFrame enabled applications to use OpenCV image and video processing routines.

2.3 Team Biographies

Trent Grover
Department: Art and Design
Major: Integrated Visual Arts (MFA)

Trent graduated from Iowa State University with my BS degree in Computer Science in 2001. Before graduating he co-founded Micoy, a company specializing in immersive video technologies. As acting Chief Technology Officer, Trent developed five patents in the area of stereoscopic panoramic video capture and display technologies. He has since returned to Iowa State to pursue my MFA in Integrated Visual Arts, focusing on novel uses of technology in the creation of interactive fine art. Trent's various experiences as a C++ programmer and computer artist helped considerably in the successful execution of the Video Output portion of this project.

Zayira Jordan
Department: Greenlee School of Journalism and Communication
Major: Human Computer Interaction (PhD)

Zayira has a bachelor's degree in journalism and a master's degree in sociocultural anthropology from Iowa State University, where her interests have included the relationship between media and culture. Throughout her career, she has dealt with both qualitative and quantitative research methodologies, and has a deep understanding of their applicability and use in market research. Zayira is excited about working with brain-computer interface because of her interest in producing interdisciplinary research with different perspectives that integrates her interest in neuroscience, anthropology and technology. She has been trained at the Greenlee School of Journalism and Communication's PhysioMedia Lab to use the EEG equipment needed for this project. She also has knowledge of various aspects of neuroscience that have proven useful for the completion of the Data Capture portion of this project.

Daniel Humke
Department: Electrical Engineering
Major: Electrical Engineering (MS)

Daniel has a bachelor's degree in Electrical Engineering, with a focus on control systems. He currently work full time for John Deere Power Systems as an engine controls and systems engineer and is pursuing a Master's degree in Electrical Engineering. Daniel has previously taken a course on random signal analysis in which Kalman filtering was used to analyze EEG signals and identify when a seizure was occurring in the subject. He also has significant experience with MATLAB that has proven valuable for the Data Analysis portion of this project.

3 Evaluation

3.1 Functional Tests

The Wake Writer system has been tested by performing a pilot study with five participants. The Data Capture portion of the project was successful in that EEG data that corresponds to the selected visual stimuli was successfully captured for five participants using the Biopac Student Lab hardware and software. The data was then successfully exported from the BSL software system for data analysis.

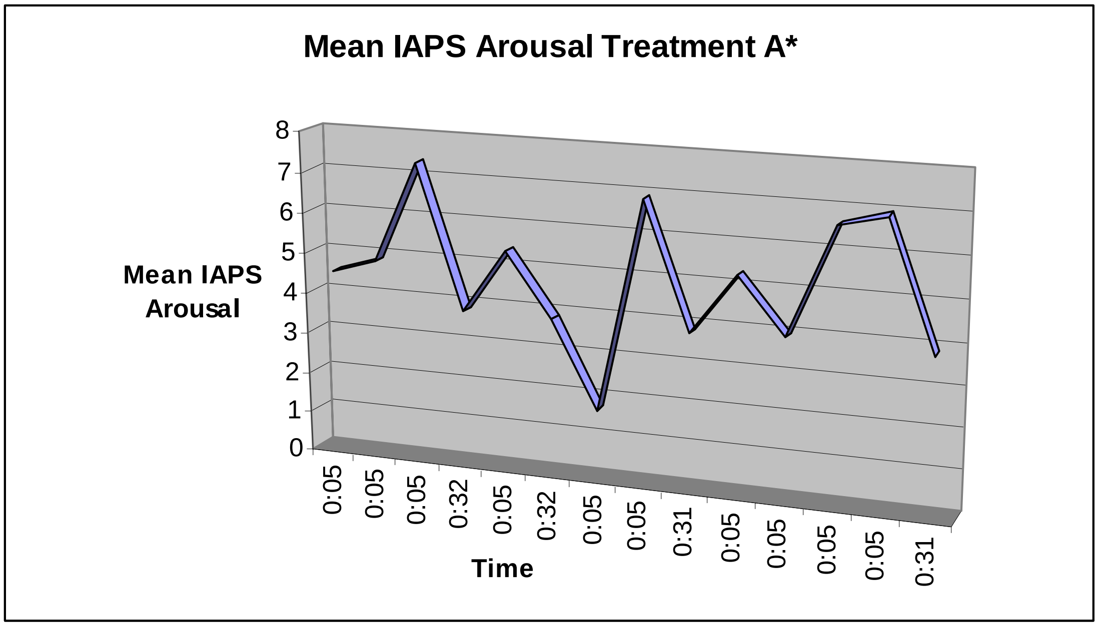
The Data Analysis portion of the project was successful in that statistical analysis of the EEG data was successfully performed using MATLAB. The EEG variance graphs appear to correlate to the data markers representing the corresponding visual stimuli.

The Video Output portion of the project was successful in that the results of the EEG data analysis successfully guide FreeFrame based video manipulations. The system also successfully appends synchronized EEG data streams to the video stream.

3.2 Experimental Results

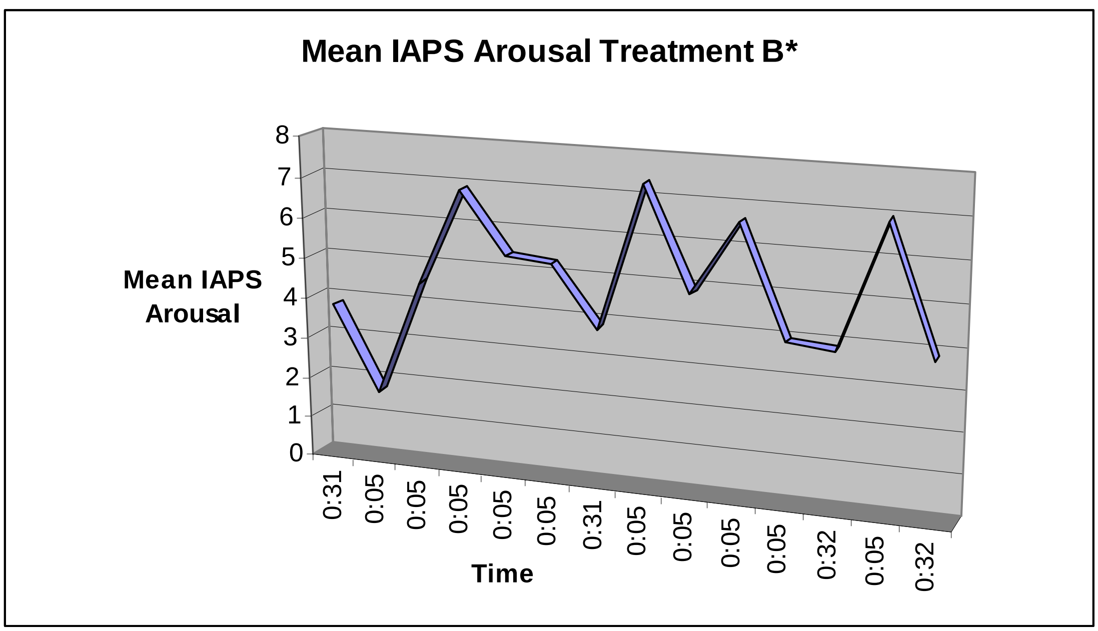
3.2.1 Expected Results

According to International Affective Picture System (IAPS), the arousal and valence values we should expect for our test stimuli are as follows:



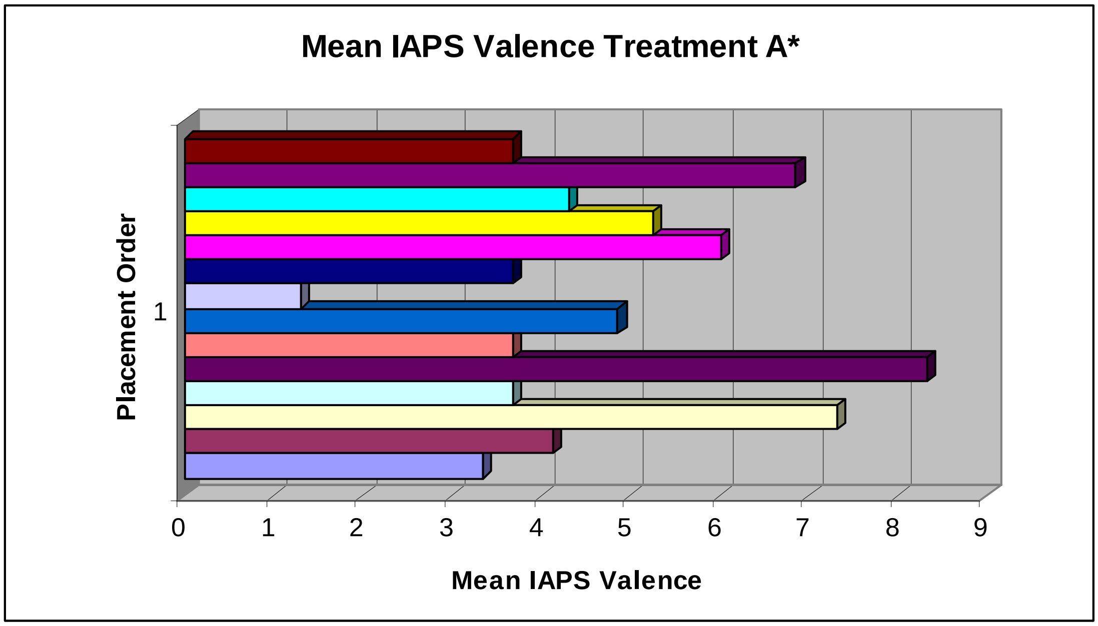
** Videos rated at mean arousal for the package*

Figure 4a: Expected Arousal Values (Treatment A)



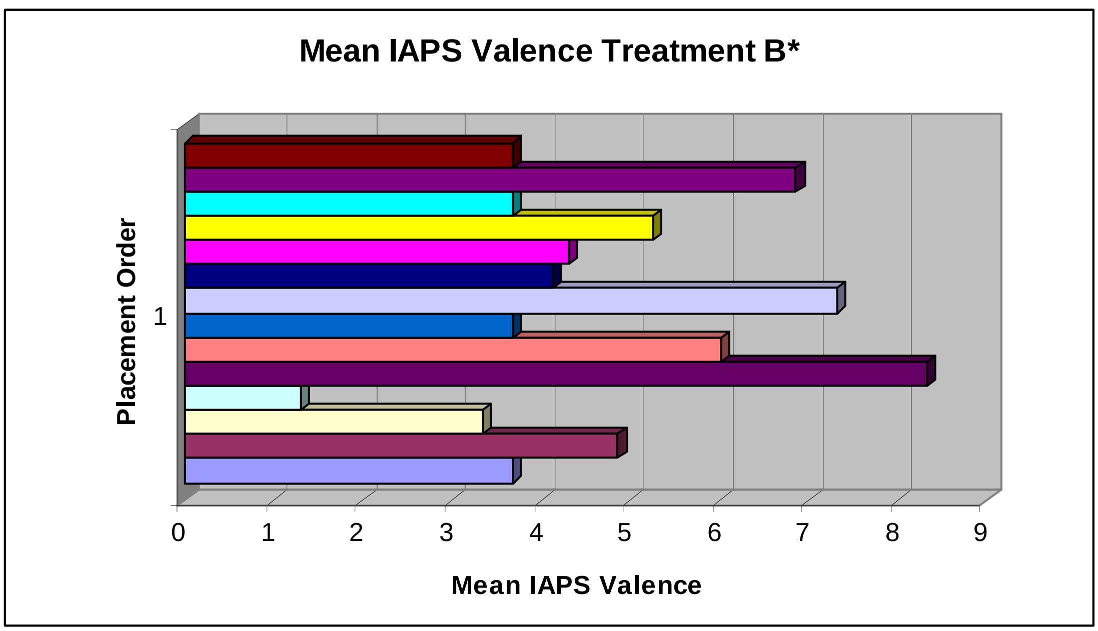
** Videos rated at mean arousal for the package*

Figure 4b: Expected Arousal Values (Treatment B)



** Positive to Negative Scale of 0 to 10. Videos rated at mean valence for the package.*

Figure 5a: Expected Valence Values (Treatment A)



** Positive to Negative Scale of 0 to 10. Videos rated at mean valence for the package.*

Figure 5b: Expected Valence Values (Treatment B)

3.2.2 Participant Data

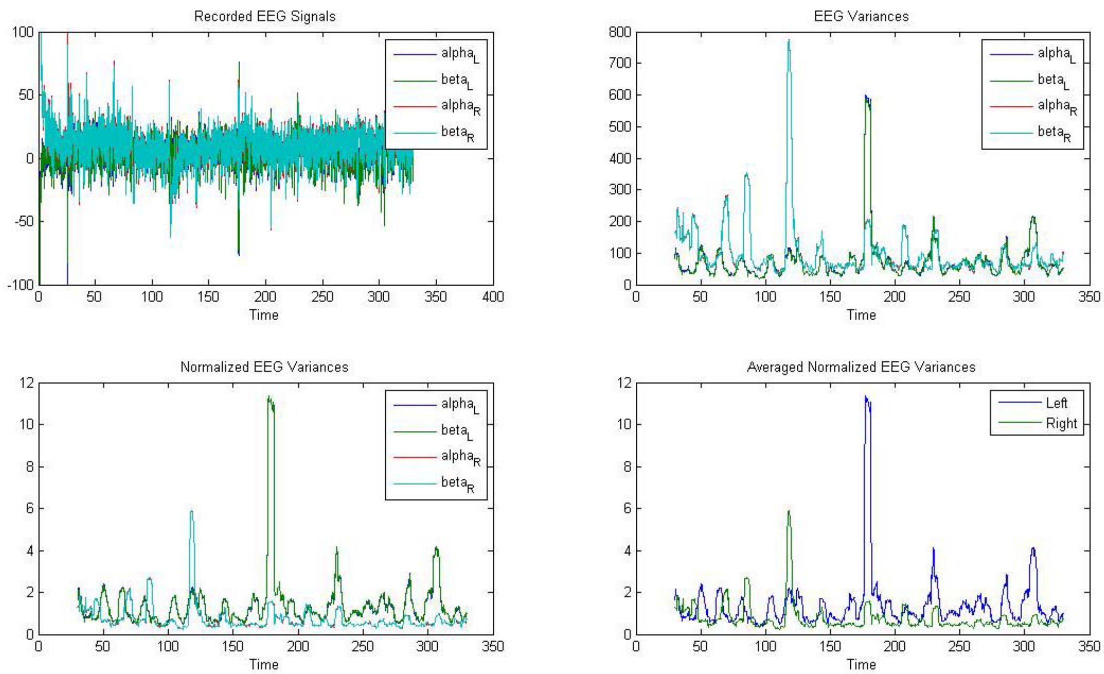


Figure 6a: Participant 1 Data Plots (Treatment A)

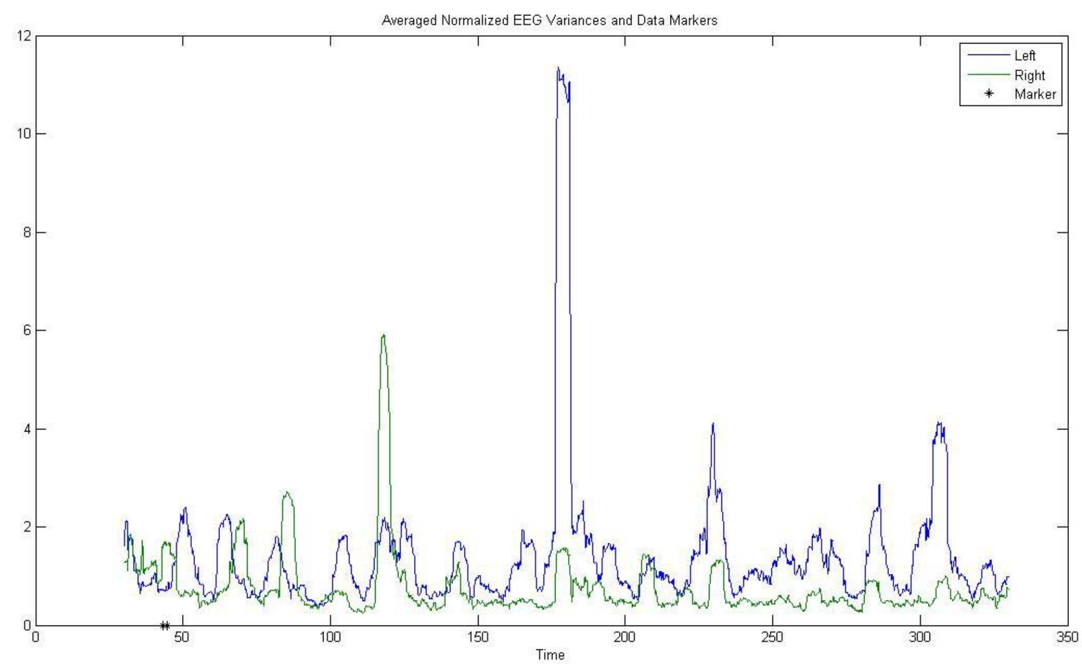


Figure 6b: Participant 1 EEG Brain Activity by Hemisphere with Data Markers (Treatment A)

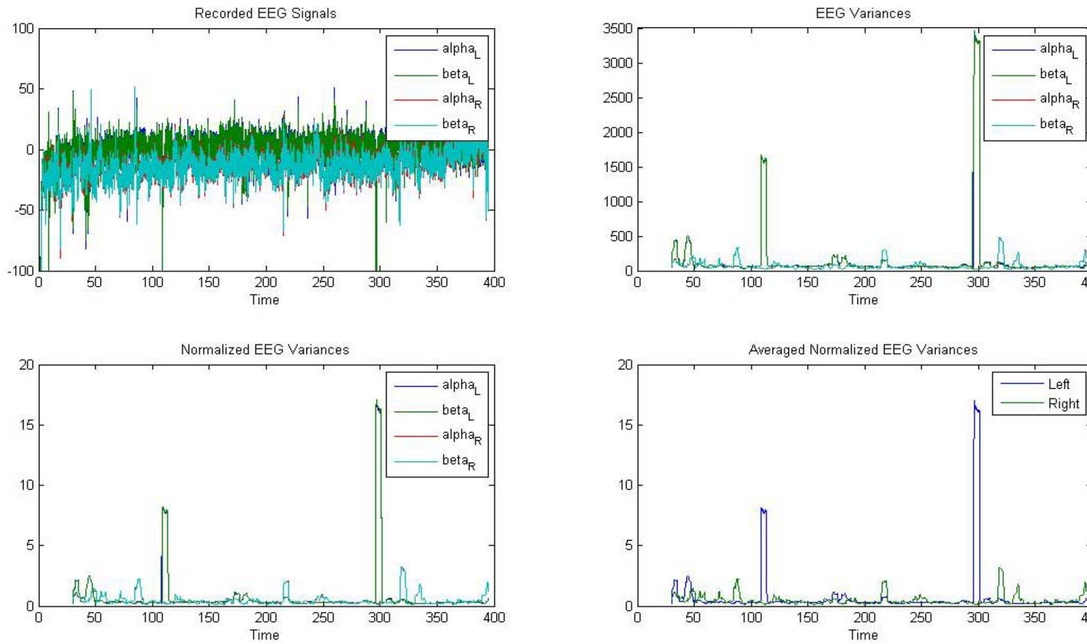


Figure 7a: Participant 2 Data Plots (Treatment A)

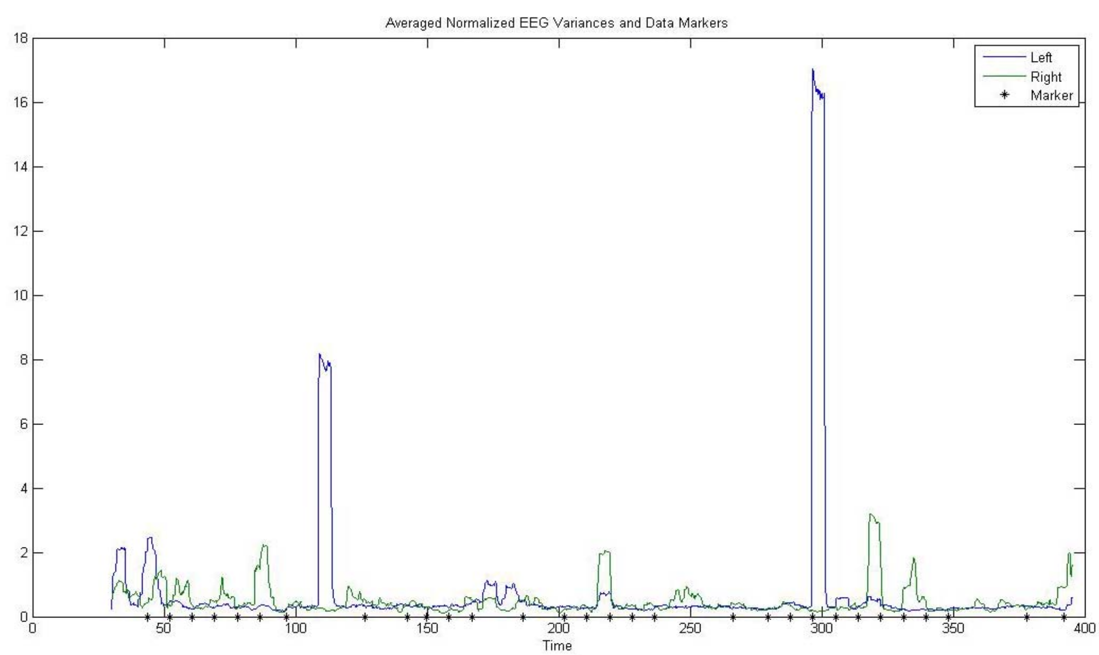


Figure 7b: Participant 2 EEG Brain Activity by Hemisphere with Data Markers (Treatment A)

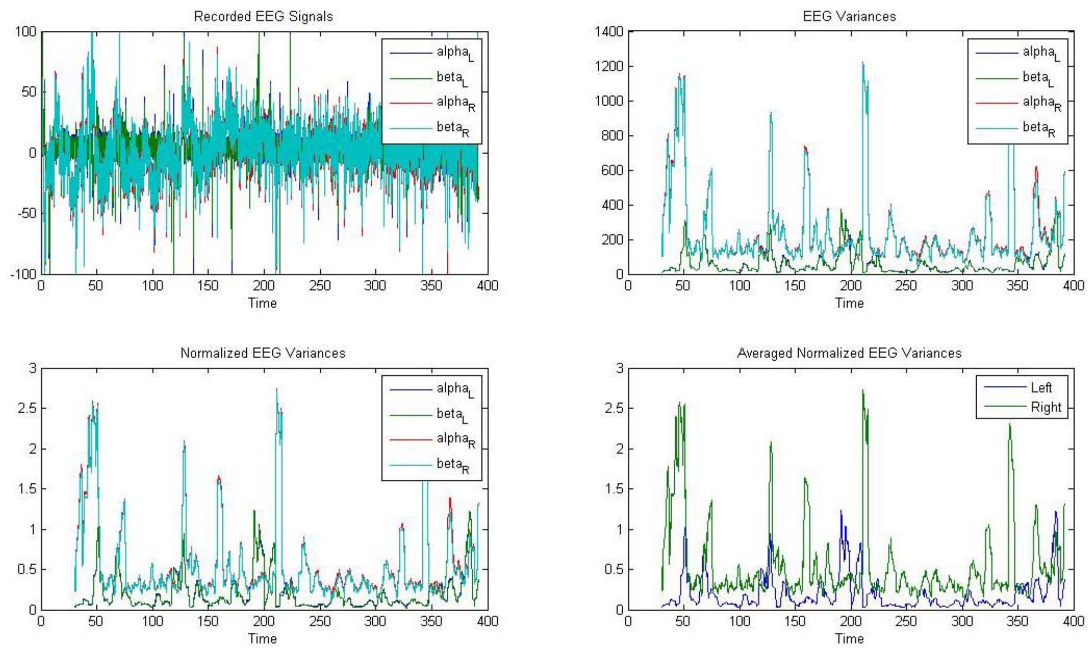


Figure 8a: Participant 3 Data Plots (Treatment B)

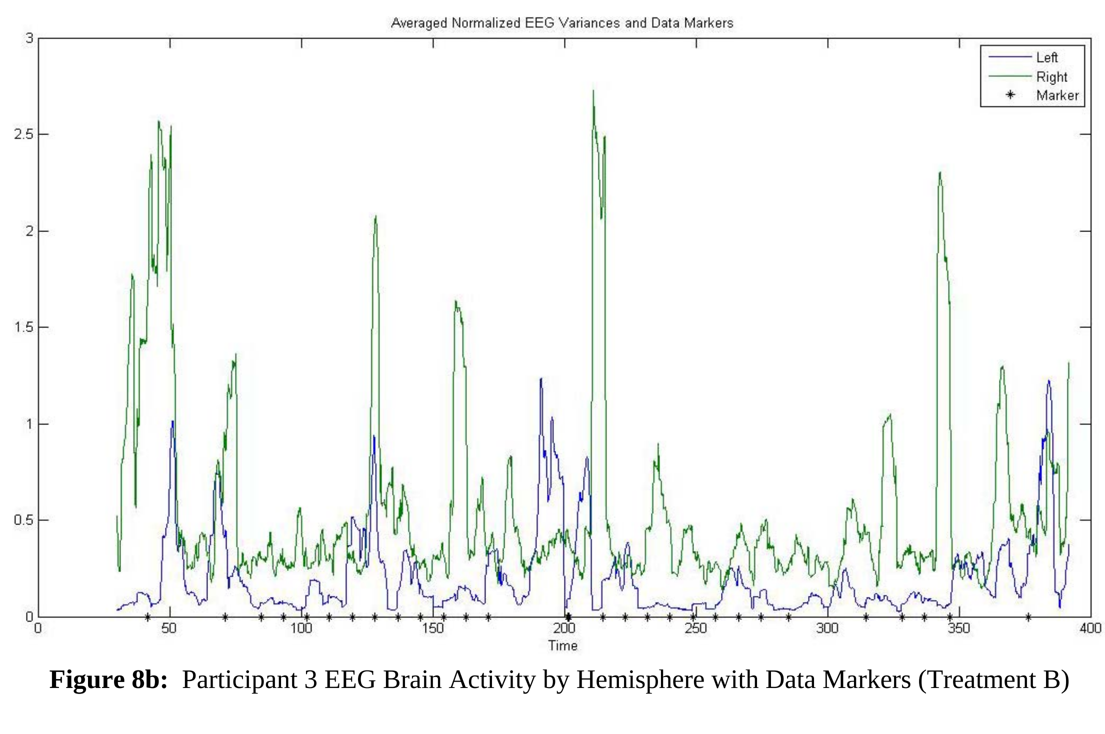


Figure 8b: Participant 3 EEG Brain Activity by Hemisphere with Data Markers (Treatment B)

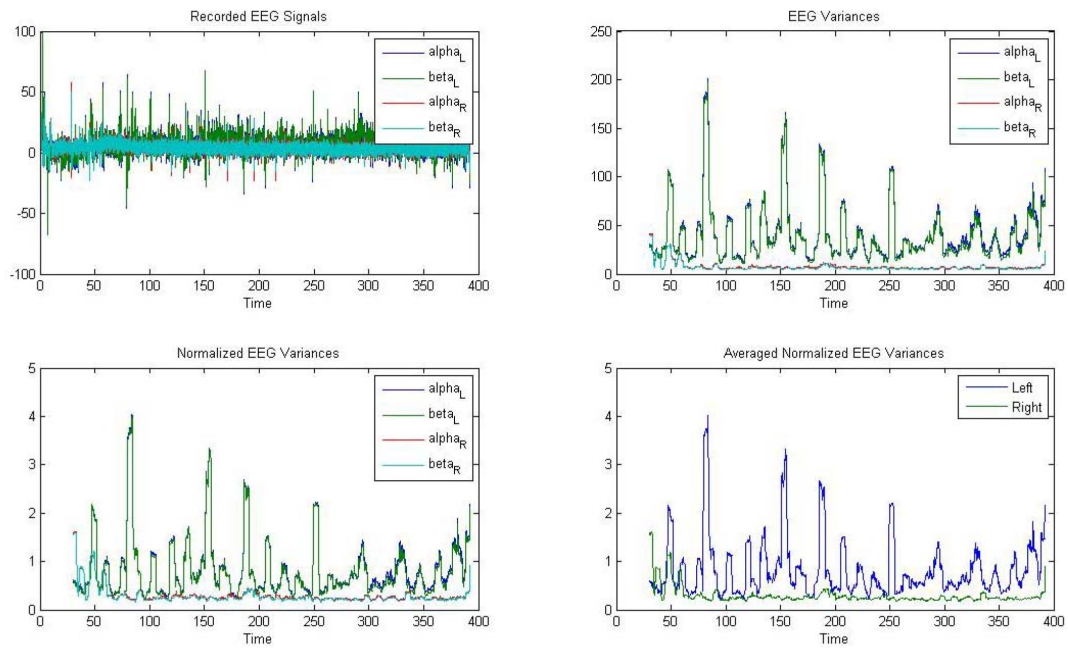


Figure 9a: Participant 4 Data Plots (Treatment B)

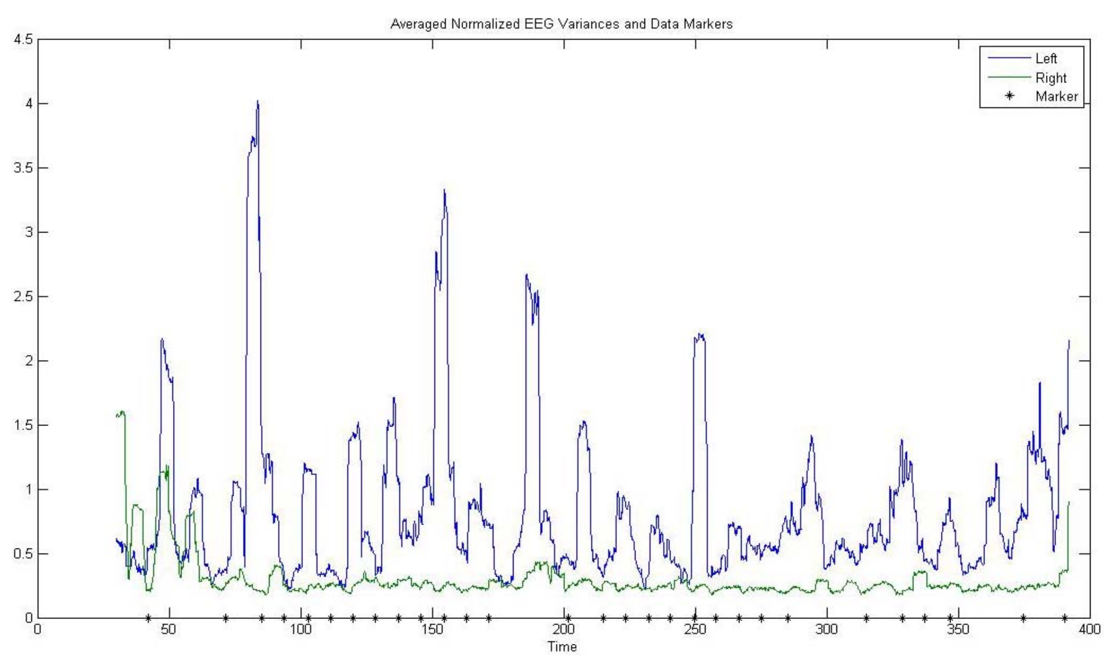


Figure 9b: Participant 4 EEG Brain Activity by Hemisphere with Data Markers (Treatment B)

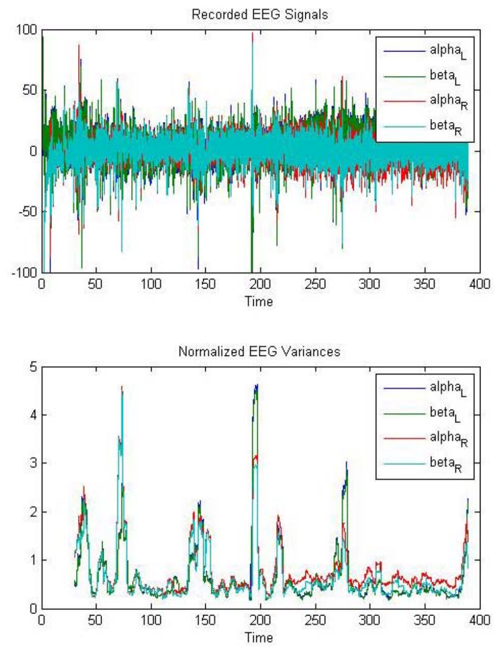


Figure 10a: Participant 5 Data Plots (Treatment A)

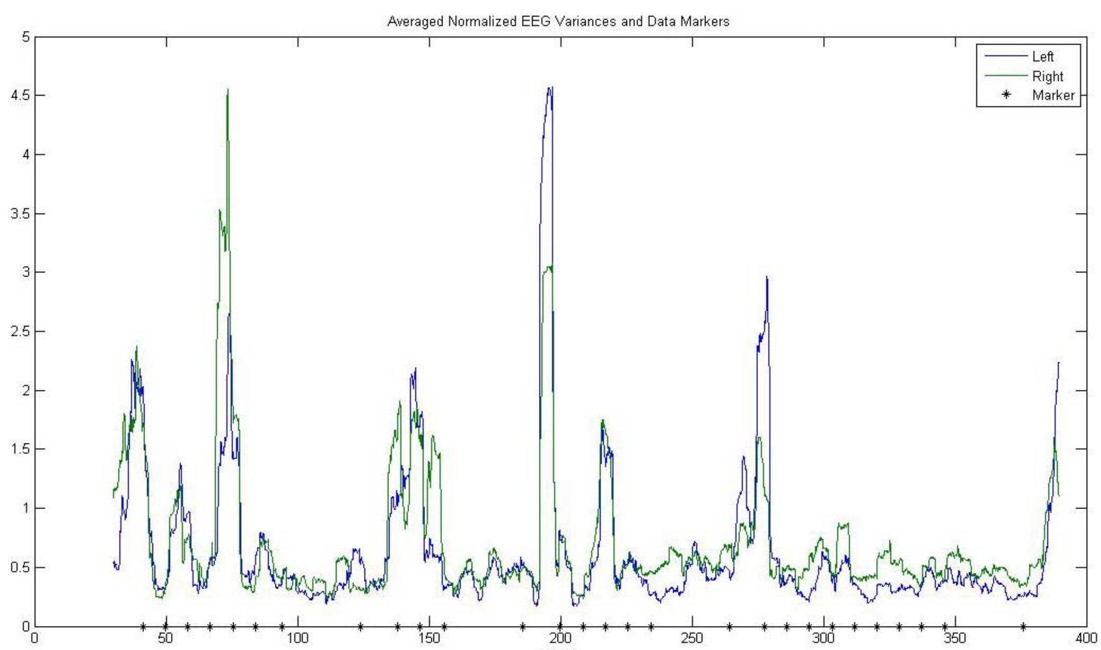


Figure 10b: Participant 5 EEG Brain Activity by Hemisphere with Data Markers (Treatment A)

3.2.3 Video Output Results

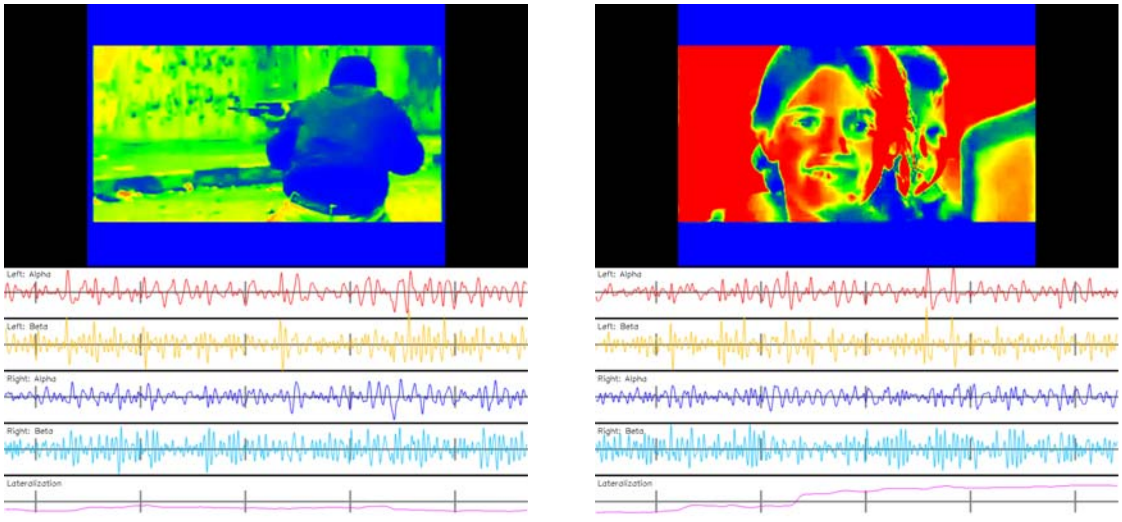


Figure 11: Video Output Samples (Scientific Mode)

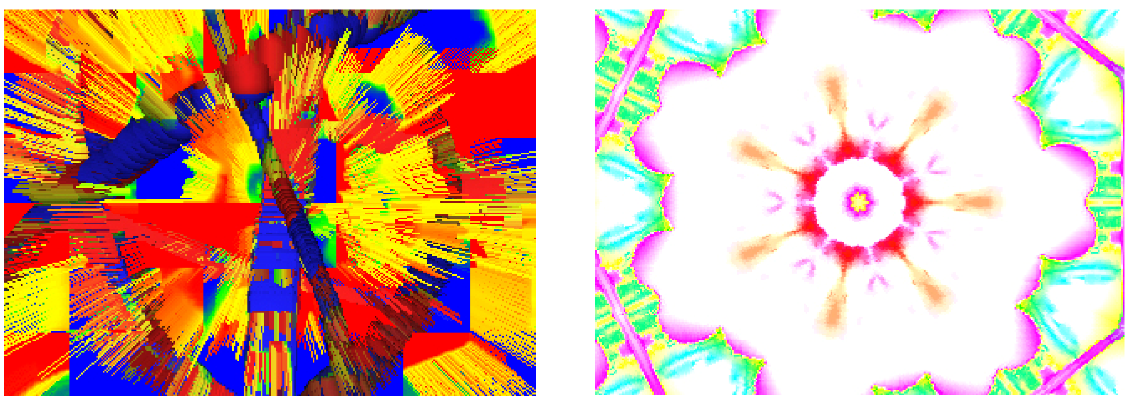


Figure 12: Video Output Samples (Artistic Mode)

3.3 Conclusions

The Wake Writer system was functionally successful in all areas, but still requires methodological adjustment to be most useful. Though the resulting EEG data shows an increase in EEG variance in correlation to our visual stimuli, this data doesn't correspond to the expected arousal and valence measurements asserted by the International Affective Picture System. Definitive, reproducible affective state characterization wasn't achieved.

However, the potential for applications that understand, reproduce, and learn from the emotional aspects of human intelligence is extensively supported by Picard (1995) in her work. In one of her examples, she proposes a system by which the responses of a user browsing a database of images are recorded and taken into account. In such an application, Picard suggests "the computer" could mark your favorites and note features that could relate to other analog images that the system comes in contact with. It could act as to understand "predictors of what you liked" and it could even be able to associate certain categories of images with certain categories of your affective responses" (Piccard 1995, p.12).

Wake Writer is intended as to delve into the possibility of our computers being able to recognize and react to our emotional states and responses. We have sought to contribute to the increasing literature on affective computing as proposed by Picard.

3.4 Error Sources

While the correlation of the data markers to the increases in EEG activity can be seen as a successful result, the lack of correspondence to the IAPS standards indicates that there are errors in our dataset. Potential error sources include participant movement during data measurement, inaccuracy of electrode placement, and many environmental factors.

Though participants were instructed to remain as still as possible, the human heart still beats, eyes still blink, and people still swallow. Since these activities are controlled by the brain, there is likely to be corruption of the measured waves (‘artifacts’) based on these natural human functions. Some existing software tools can be used to perform ‘artifact rejection’, which is an advanced analysis to attempt to remove the majority of these artifacts from EEG data.

Environmental or extraneous factors linked directly to the participants are also potential error sources. Depending on what events are occurring in their lives, the same participant may respond differently to the same set of images. By performing repeated trials of this experiment, this error source could be reduced.

3.5 Future Work

The Wake Writer project represents a good first step towards an affective video documentation and manipulation system, but there exists a great deal of potential for future work.

The most important work remaining is to identify and compensate for any of the aforementioned error sources. Similarly, the size of the population selected to participate in this pilot study is quite small, and an accurate representation of the population is probably not well represented. Future work could also be done with a much larger audience of participants.

This incarnation of Wake Writer was unable to attempt a real time system because of hardware limitations of the Biopac Student Lab system used. The video output portion of this system is capable of real time video manipulation based on incoming data signals, but a complete real time system would require work on real time EEG capture and signal analysis.

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[1] Image from The Ten Twenty Electrode System. Electroencephalography and Clinical Neurophysiology. Committee on Clinical Examination in EEG Vol. X, 1958.