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The effect of 3D/motion perception on the P300 response

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2009 April 3

Abstract

Past research has shown that perceiving 3D and moving stimuli increases neural activity, but it is not known whether it can affect the P300 response. In this study flashing target letters were presented on a computer screen in 3D and in motion to potentially increase the strength of the P300 response. EEG scalp electrodes were used to record brainwaves. The P300 response occurs 300 milliseconds after target stimuli are presented. Brain-Computer Interface: 2000 (BCI) was used to identify the P300 response. When the BCI detects a P300 response, it uses this response as a cue to indicate what target letter the brain was reacting to. BCI2000 has been developed for paralyzed people as a way of communicating. The effect of the stimuli was not statistically significant in this experiment; however, future implications are discussed.

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The brain's response to visual perception has been studied many different ways. More specifically the brain's response to 3D stimuli and environments has recently been a focus of investigation in pursuit of understanding perception in real world environments. The localization of 3D perception in the brain has been measured through functional magnetic resonance imaging (fMRI) and has revealed that the lateral occipital complex (LOC) is essential in perceiving 3D stimuli (Moore & Engel, 2001). The localization of 3D perception in the brain is an important finding, however, this is only part of the story; more research needs to be done. Within our environments our perception of 3D space goes hand in hand with our ability to move and perceive motion (Wexler, & Boxtel, 2005). To further understand how these processes that psychologists and neuroscientists are measuring in controlled laboratory settings more consideration of how these systems operate in our everyday life is needed. The way that 3D/motion perception operates at the neuron, the contributions of other brain regions, and the characteristics of this activity are not apparent through fMRI data. Another way in which neural activity can be measured in regards to 3D/motion perception is through EEG recordings of a very specific response, the P300 response.

Since the 1960's the P300 response has been studied through EEG recordings which has fostered a substantial amount of literature and a great understanding of the P300 response in the brain (Polich, 2007). The P300 is an event-related potential measured as electrical activity when neurons are transmitting information to one another. The P300 can be identified as a specific electrical response in the brain 200-400ms after a target is presented; this activity is considered in terms of the mass action of neurons not in local regions (Wolpaw, Birbaumer, McFarland, Pfurtscheller & Vaughan, 2002; Krusienski, Sellers, Cabestaing, Bayoudh & McFarland, 2006).

Everything that has been studied (from alcoholism to target discrimination) has contributed to understanding the importance of the P300 response (Polich, 2007). More recently the neural substrates of the P300 response have been identified as part of the locus coeruleus-norepinephrine (LC-NE) system (Nieuwenhuis, Cohen & Aston-Jones, 2005). The P300 response is modulated by the LC-NE which together reflects stimulus evaluation and decision making processes responsible for determining the presence or identity of task-relevant stimuli. This process and the P300 typically occur within 200-400ms after a target stimulus is presented and it is also known to potentiate the response to motivationally significant events. The amplitude of the P300 indicates the strength of the response and is known to vary considerably from person to person but remain consistent in people over time (Nieuwenhuis et al, 2005; Polich, 2007).

With such a great deal known about the precise way to measure the P300 response to stimuli, neuroscientists, computer scientists and engineers developed a brain-computer interface (BCI) in 2000 called BCI2000 which uses the P300 response to indicate the selection of target stimuli in an array of letters, numbers or characters on a computer screen in order to spell out a target word letter by letter as part of the P300 speller within BCI2000 (Wolpaw et al., 2002; Schalk, McFarland, Hinterberger, Birbaumer & Wolpaw, 2004; Krusienski, Sellers, McFarland, Vaughan & Wolpaw, 2007). This BCI2000 program operates with a portable EEG device connected to a computer and an electrode cap which is placed on the scalp of an individual. The target characters which the computer has matched from the timing of the stimulus presentation and the timing of the brain's P300 response is then displayed instantly at the top of the computer screen (Wolpaw et al., 2002). This specific BCI was built as a communicative tool for disabled people mainly patients with amyotrophic lateral sclerosis (ALS) who cannot make the muscle movements to speak or write, and the BCI2000 program is used with patients all around the world to operate computers and to send emails (Sellers & Donchin, 2006; Hoffmann, Vesin, Ebrahimi & Diserens, 2008).

Research using the BCI2000 program has been conducted using ALS patients as well as non-disabled individuals and has fostered improvements in the platforms performance. Some studies have looked at ways of improving the data being analyzed through statistical measures like stepwise linear discriminant analysis (Krusienski et al., 2007) and others have considered stimuli characteristics such as the size of the array and the inter stimulus intervals on performance (Sellers, Krusienski, McFarland, Vaughn & Wolpaw, 2006). Perceptual experimentation with the BCI2000 program allows researchers to examine the brain's response from the surface of the scalp to various kinds of stimuli. The exactness and reliability of the BCI2000 program makes it an ideal measurement tool for studying various aspects of perception and decision-making processes, such as the perception of 3D/motion perception. By manipulating the letters of the BCI2000 P300 speller to be 3D images moving closer to the participant P300 amplitudes can be measured to assess the difference between the regular 2D stationary lettered display and the 3D/motion display.

Researchers have attempted to recreate a complex 3D perceptual stimulus while using EEG recordings to measure its effects on participants viewing random dot stereograms similar to the popular "Magic Eye" pictures (Burgess, Rehman & Williams, 2002). The EEG data analyzed did not consider P300 amplitudes as an area affected by 3D stimuli. Also, participants were required to press a button when they started to search for the hidden 3D image, when they found it, when they stopped viewing it and when they began resting. In 2001, Salisbury, Rutherford, Shenton & McCarley looked at the effect of button pressing on the P300's amplitude, latency and topography. They found that the behavioural response of button pressing created motor potentials from movement which distorted the measurement of the P300 as well as other ERP data. This finding highlights a potential confound in the Burgess et al., 2002 study which required multiple button pushing responses. The BCI2000 speller program does not require a behavioural response; the exact stimulus onset can be matched with the data collected from the brain signals.

It has been hypothesized in past research that 3D and motion stimuli are more complex than 2D stationary stimuli and that these more complex stimuli elicit more neural activity which can be measure using EEG data. Perceiving stimuli that were created to be increasing in complexity from a fast flash of the letter to a gradual brightening of the letter should increase the amplitude of the P300 response measured by EEG data. Also perceiving motion and motion in 3D the P300 amplitude should increase even more so than the gradual brightening flash.

This study provides more information regarding the effect of stimulus properties on the P300 as well as the effect within the BCI2000 P300 speller. This information could be useful for future studies with the BCI2000 P300 speller and in other perceptual studies regarding 3D and motion stimuli.

Recreating real-world situations in which to measure the P300 response can provide evidence for its function as well as provide even more information regarding how it works. By considering 3D qualities as well as motion in the stimuli presented P300 amplitudes may be affected much differently than when they are traditionally studied in the laboratory. This evidence could be useful for future 3D perceptual experimentation and for research done in virtual reality environments (Waller, Beall & Loomis, 2004).

Method

Participants

The participants in this study consisted of 10 volunteers (students, staff and faculty) from the Algoma University campus. There were no demographic or participant characteristics required for this study. Participants were given a written consent form which included details about the study, what they could expect. Before the procedure started they were directed and given verbal details about what to expect. All of the data were collected over 7 days and each participant completed the study in one session lasting approximately 45 minutes.

Materials

Computer Programs

The experiment was conducted using BCI2000 software developed by Wolpaw, Birbaumer, McFarland, Pfurtsceller, & Vaughan (2002), available online at http://bci2000.org. The BCI2000 program receives the brainwave data gathered from the 8 channel EEG cap as well as operates and records details about the timing of the stimuli being presented (Wolpaw et al., 2002). This program requires an 8 channel EEG cap and the GMOBIL lab portable EEG machine to record brainwave activity (see Figure1). The P300 speller was used which is one of the BCI's within BCI2000 the stimuli of the P300 speller is a 8 × 9 matrix of letters and other characters displayed on a computer screen (see Figure 2). This system also provides feedback to the user (what character they are viewing) normally when it is in use (Wolpaw et al., 2002), for the purposes of this study feedback was not used due to time constraints. The BCI2000 program was designed to be flexible, where aspects could be changed (programmed) at any step in the system (Wolpaw et al., 2002). The way that the program interacted with the stimuli was altered for this experiment. The normal flashing characters used in the BCI2000 speller program were recreated and three other stimuli were added. The program was changed to present the visual graphics on a secondary machine (Linux operated PC) networked to and sending information to the primary (Windows operated PC) machine. The program was altered to present several series of pictures as an array to simulate flashing or moving stimuli.

Stimuli

There were four different 8 × 9 letter matrix stimuli being presented in this experiment. The standard fast flash, the gradually brightening flash, the 2D motion and 3D motion stimuli were all created from the same pictures of real 2D letters moving in space and were designed to be as similar as possible to the existing 8 × 9 matrix found in the BCI2000 P300 speller program (see Figure 3 and Figure 4). A 4 foot x4 foot real-life matrix of letters was built where letters were attached to rods which moved back closer to the back of the board. Each rod was moved equally for each picture and left-eye and right-eye pictures were taken at each of the 16 levels marked on the rods. This created a series of pictures depicting letters moving in and out from the background. The images were further processed using MATLAB to include a textured background, a better way of indicating ground than a flat black computer generated background. The left-eye and right-eye images were resolved in MATLAB as well. The stimuli in this experiment are now built in to the BCI2000 P300 speller program as an option for stimulus presentations so it can be used in more studies and made available at http://bci2000.org.

Stimuli Presentation

Participants sat approximately 26 inches from the 27' monitor which displayed the stimuli graphics. The red/cyan 3D glasses were worn for each of the stimuli presentations, although they only worked to make the stimuli 3D in the 3D stimuli condition. The order of the stimuli being presented was randomized for each participant prior to their appointment. The primary computer was operating the BCI2000 P300 speller and was networked to the secondary computer displaying the stimuli matrix which was also operating through the BCI2000 P300 speller program.

Procedure

After each participant read and signed the consent form the EEG cap was placed on their head and the conductive gel was inserted into each of the 8 electrodes on the cap EEG cap. The cap was then connected to the GMOBIL lab portable EEG which was connected to the primary computer operating BCI2000. The stimuli presentation was selected within BCI2000 and loaded on to the secondary computer operating the 27' monitor displaying the stimuli one at a time. The participants were then given directions regarding their target stimuli. The word "BRAIN" was entered into BCI2000 parameter file for each participant as text to spell. With the word "BRAIN" located in the top left corner of the screen the participants were instructed that their first target letter was "B" and that each target letter would either have 10 fast flashes, 10 gradually brightening flashes, 10 2D moving characters, or 3D moving characters and that they should count to themselves (not out loud) each time their target flashed/moved. Participants were informed that their target letter was not the only letter that would flash/move and that this would occur for other characters as part of a random flash/motion group. The importance of only looking at the target letter and to not look at any other character was described in regards to the P300 response which only occurs for target responding and is hindered by perceiving any other characters on the screen. The participants were also informed that after every target letter flashed/moved 10 times there would be a 3 second pause (where no characters would be flashing/moving) before the next target letter should be viewed (i.e. change from “B” to “R”) and that they should remain completely still as movement of any kind can interfere with EEG data. In total each participant was exposed to all four of the stimulus types. Each participant was asked if they understood the directions and if they had any questions before the experiment began.

Statistical Analysis

The BCI2000 P300 speller program computes correlations between average channel values and whether or not the stimulus is a target or not. These values are displayed as R^2 which represents the strength of the response to a target stimulus and the latency at which the R^2 value is the greatest. The R^2 values were recorded as the peak of the response and also the time that these peaks occurred. A one-way ANOVA was used to compare the four different stimuli types and the R^2 value as the peak of the response to assess whether these stimuli were statistically significant. Another ANOVA was conducted between the latency of the peak and the stimulus type.

Results

A one-way ANOVA revealed that there were no statistically significant differences found between any of the four stimuli responses in their R^2 values (strength) or in the latency when the R^2 peaks occurred (see Figure 5). However, the BCI2000 P300 speller program was able to identify target responses in all of the stimuli conditions meaning that they all successful in eliciting a target response when a participant was viewing a target. Further analysis would benefit by considering a participants accuracy of performance rather than the strength of the P300 response, as there may be other factors influencing performance such as non-target responding.

Analysis of the individual channels averaged over all ten participants for each stimulus type is depicted in Figure 6. The fast flash stimulus yielded a clear P300 response between 200 and 400 milliseconds; however, the other three stimuli did not yield clear P300 responses. The gradually brightening flash, 2D motion and 3D motion show a different kind of responding to more complex stimuli than the fast flash.

The latency of the target responses were varied, but were not statistically significant (see Figure 7). Typically, the P300 response occurs 200 to 400 milliseconds after a target stimulus is presented. The latency of the peak amplitude for the fast flash is in accordance with other P300 research. The latency of the gradually brightening flash, the 2D motion and the 3D motion peak amplitudes are less in accordance with P300 research in that they do not fall between 200 and 400 milliseconds after a target stimulus is presented. The largest difference is found between the fast flash and the 2D motion although this difference was not statistically significant.

Discussion

All ten of the participants were found to have had responses sufficient enough for the BCI2000 P300 speller program to detect those responses as target responses. The clear P300 responding to target stimuli for the fast flash stimuli is in accordance with previous studies (Sellers et al., 2006). The three more complex stimuli created for this experiment were not successful in eliciting typical P300 responding.

The difference in latency between 2D and 3D motion larger than would be expected however was not statistically significant. The 2D motion stimuli and 3D motion stimuli were identical in the way that they behaved except that 3D was more exaggerated by its perceived popping out of the screen. The 3D motion stimuli elicited similar latency to the fast flash and gradually brightening condition suggesting that motion alone does not have an effect.

The BCI2000 P300 speller program provides an ideal stimulus presentation and response measuring system for research regarding the P300 response in the brain which psychological research regarding the brain's response to various kinds of stimuli can benefit in future studies. Although the stimuli created for this experiment did not seem to have an effect, further research into different kinds of stimuli may be useful for the BCI2000 P300 speller. The ALS patients who use the BCI2000 P300 speller have unique abilities and providing them with a choice between different kinds of letter matrices could be beneficial depending on their needs.

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Figure Captions

Figure 1. Dashed lines represent the 8 Channel EEG cap used in the experiment and in BCI2000's P300 speller program. Solid lines represent electrodes on a 64 channel cap.

Figure 2. A screen shot of the standard 8 × 9 character matrix used in BCI2000 P300 speller program.

Figure 3. A screen shot of the experimental 8 × 9 character matrix designed for this study and used for the fast flash, gradually brightening flash and the 2D motion stimuli.

Figure 4. A screen shot of the experimental 8 × 9 character matrix designed for this study and used for the 3D motion stimuli only.

Figure 5. Boxplot of the stimuli and peak amplitudes measured by R^2. The x axis shows the stimulus types and the y axis shows the peak amplitudes measured by R^2 values. The peak responses for the fast flash show the most variability with 50% of the responding occurring between 0.0030 and 0.0175 R^2. The responses for the gradually brightening flash, 2D motion and 3D motion show Similar responding ranging from 0.0075 and 0.0135 R^2.

Figure 6. Each coloured line represents the data from each of the 8 electrode channels averaged over all 10 participants. The black lines represent the non-target responding of all of the electrode channels. Top-left: The fast flash shows a normal P300 response at 300 milliseconds over most channels. Top-right: The gradually brightening flash shows a strong response with a

longer latency. Bottom-left: The 2D motion responses occur immediately and return closer to zero by 500 milliseconds. Bottom-right: The 3D motion responses occur at 500 milliseconds.

Figure 7. Boxplot of the time in milliseconds when the peak R^2 occurred for each stimuli type. The x axis shows the stimulus types and the y axis shows the time in milliseconds. The boxes represent 50% of the data for each stimulus type.

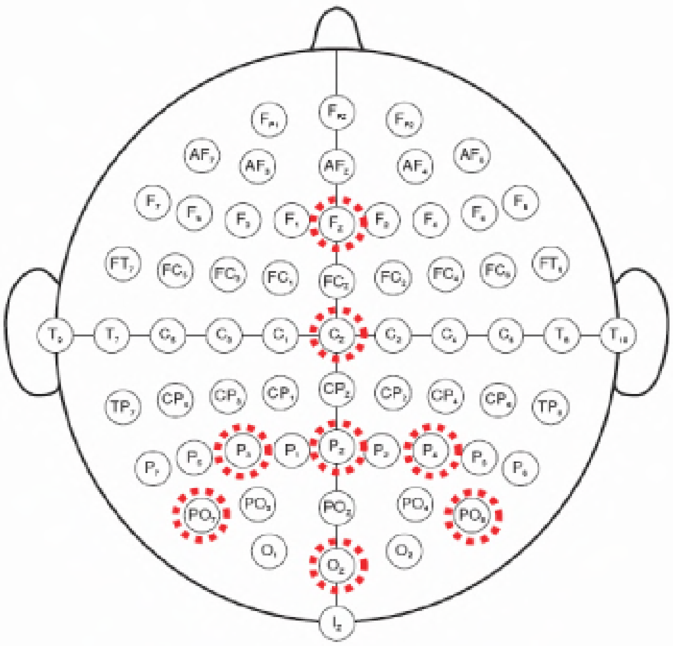

Figure 1.

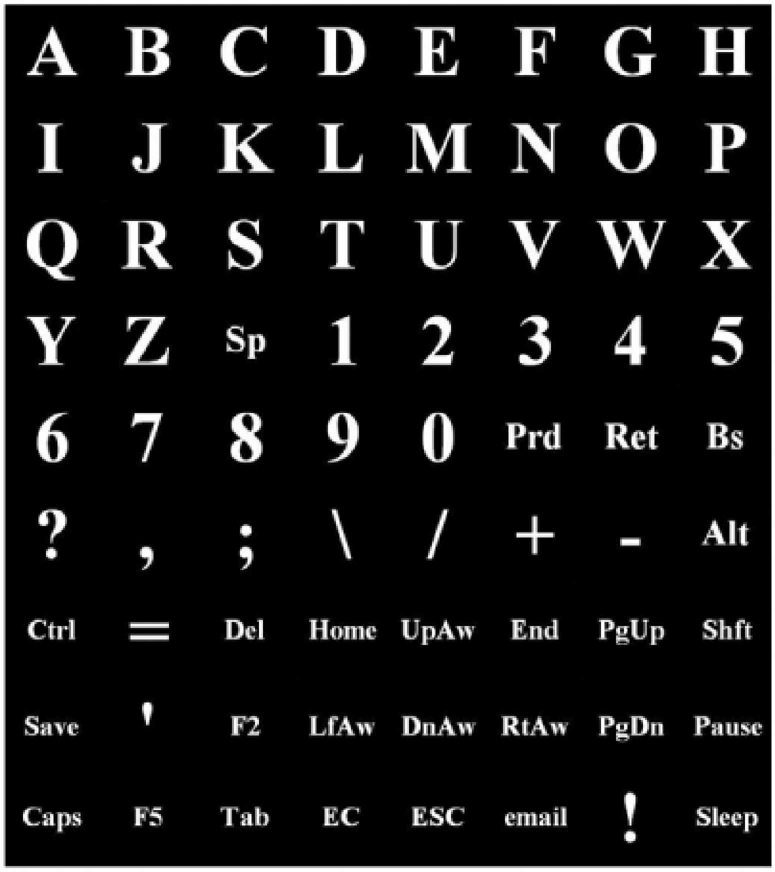
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Figure 2.

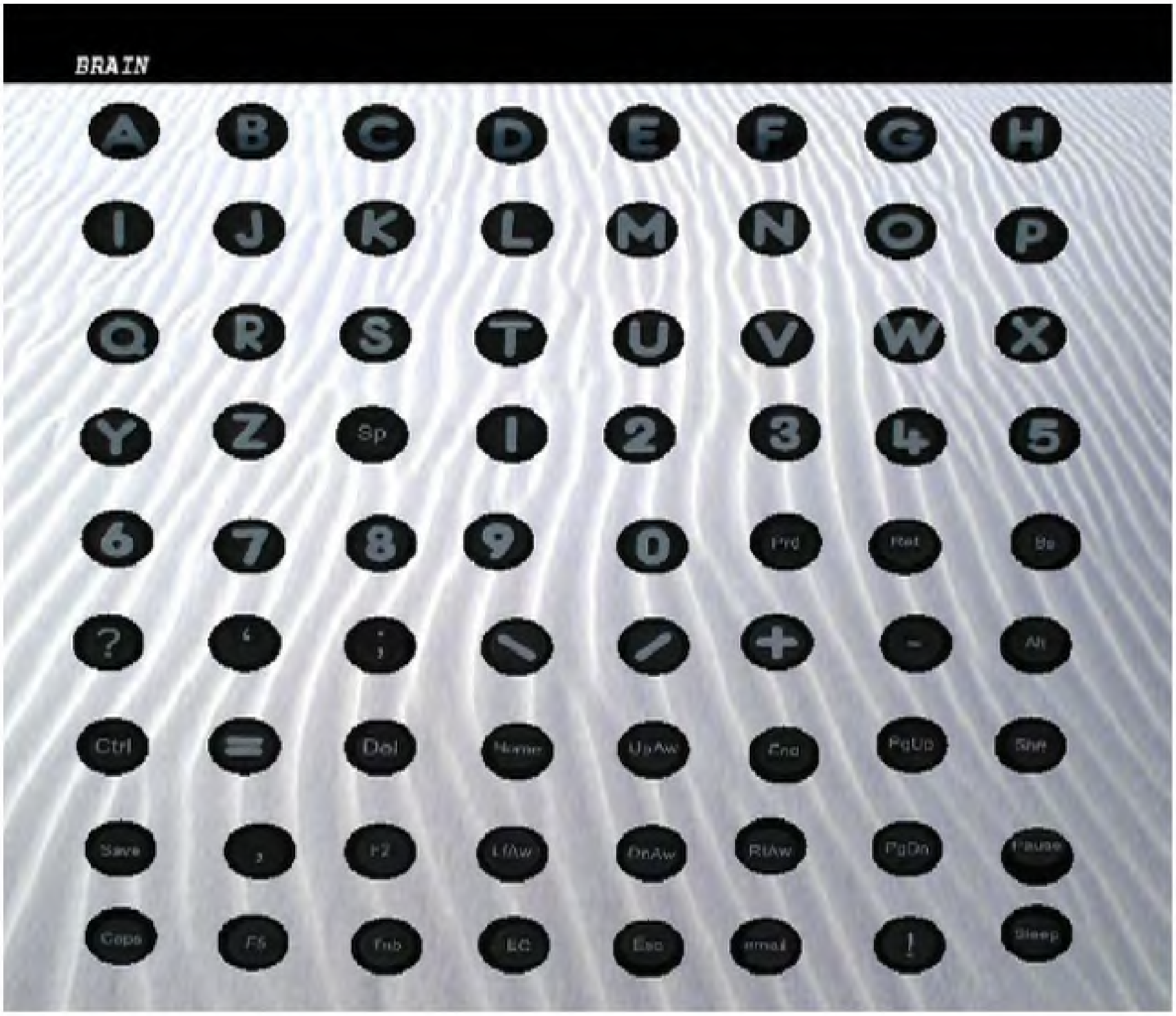
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Figure 3.

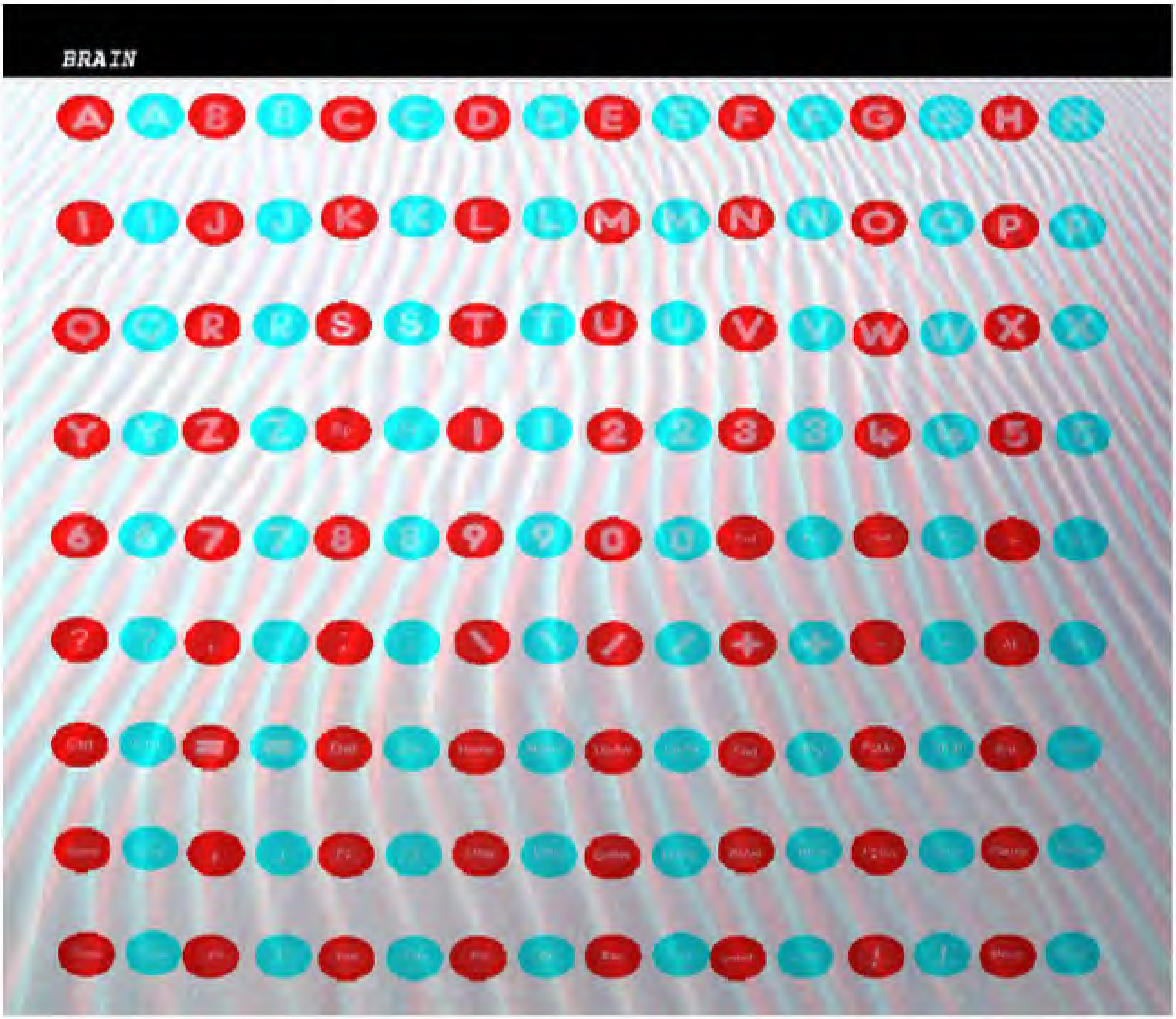
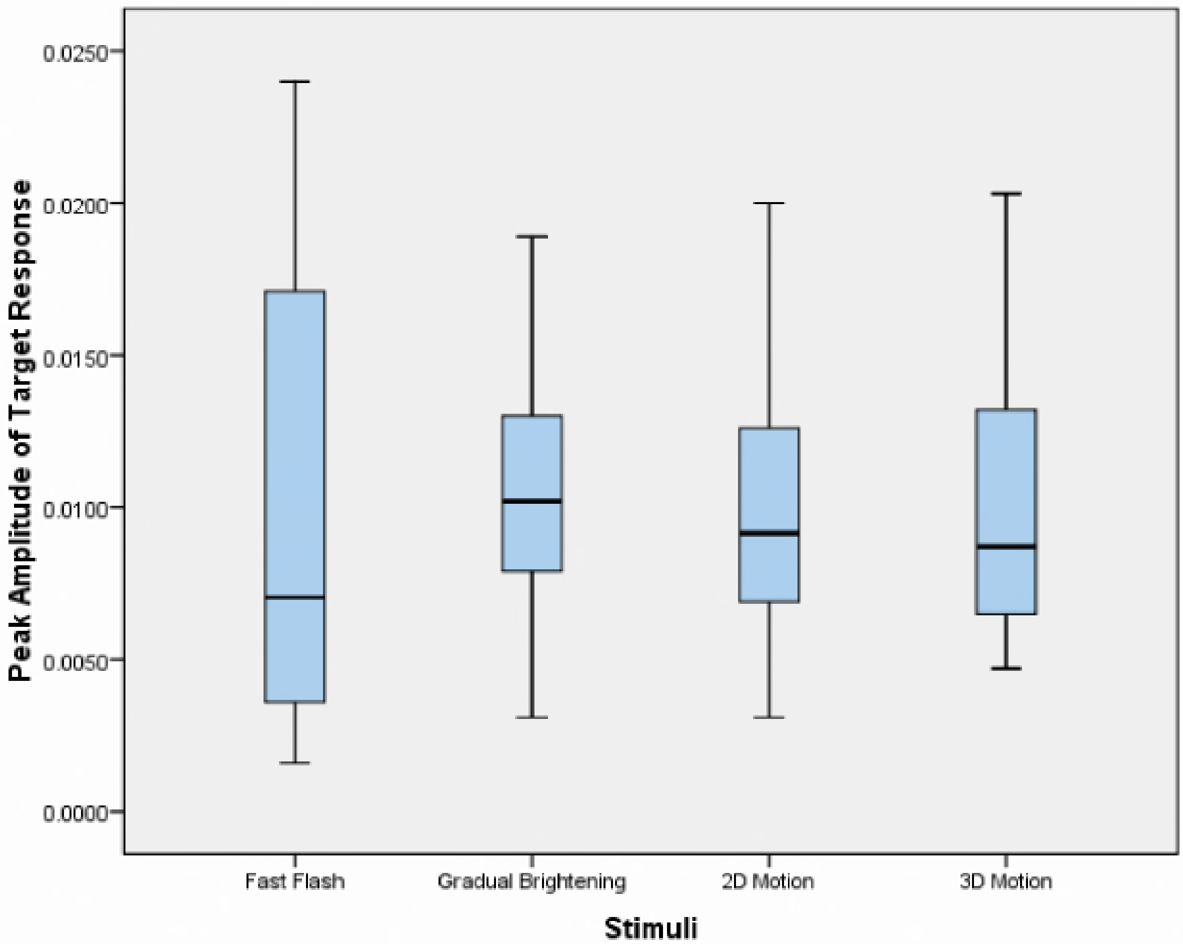


Figure 4.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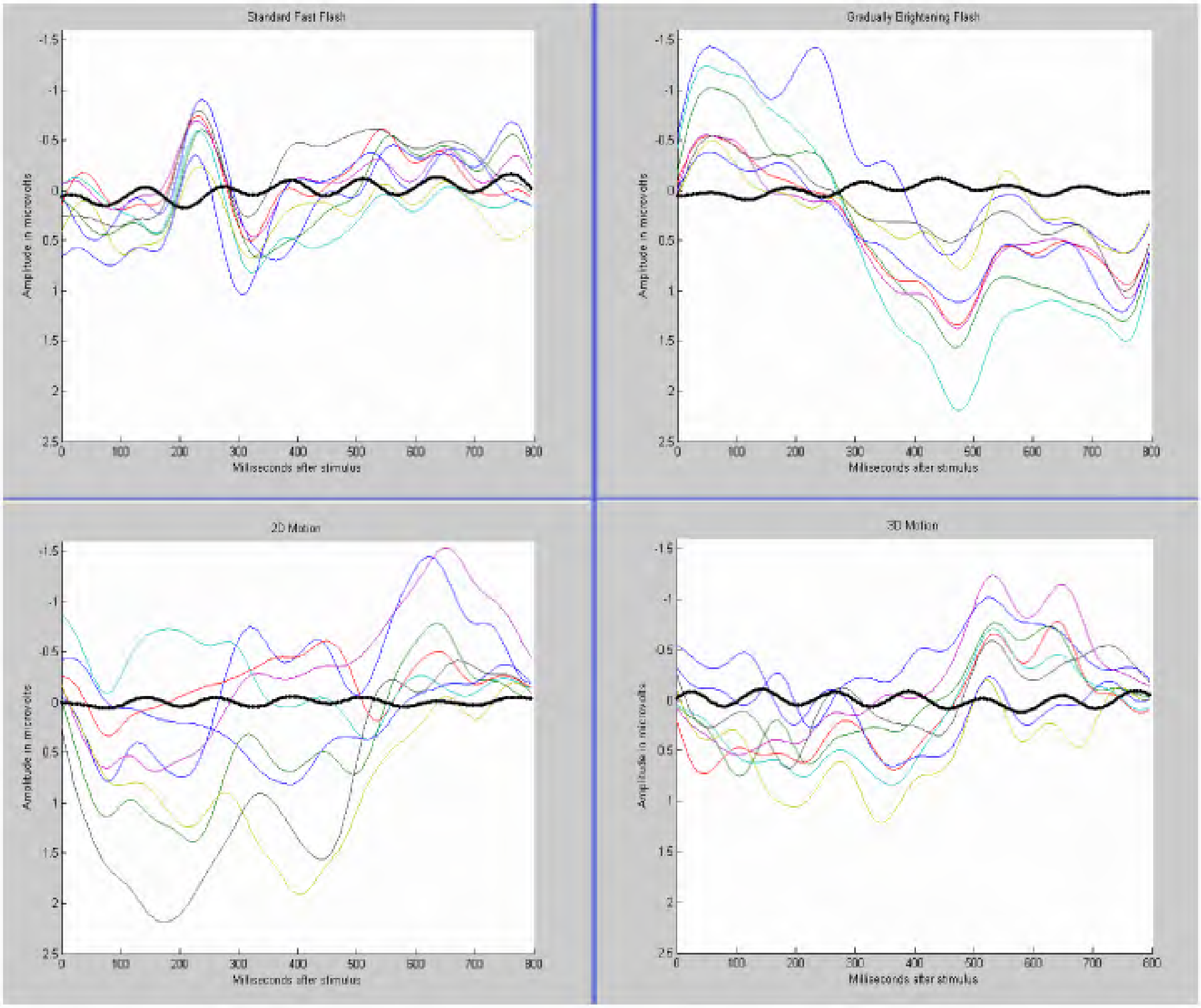
Peak Amplitude of Target Response
Fast Flash
Gradual Brightening
2D Motion
3D Motion
Stimuli

Figure 5.



Standard Fast Flash
Gradually Brightening Flash
2D Motion
3D Motion
Amplitude in microvolts
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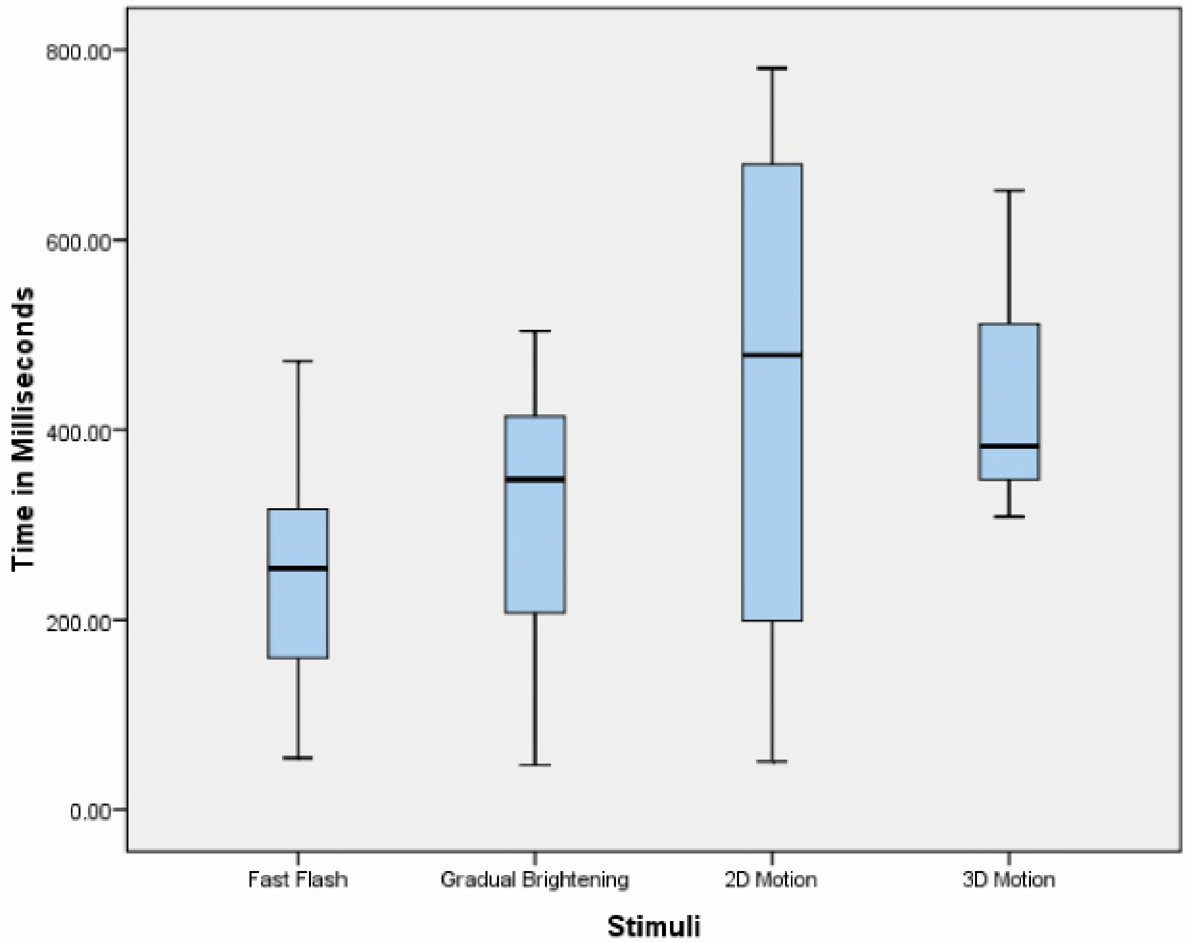
Figure 6.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2D Motion
3D Motion
Stimuli

Figure 7.