BCI effectiveness test through N400 replication study

Thomas Ousterhout
University of Copenhagen / Njalsgade 136, building 27, 2300 Copenhagen S
tko@hum.ku.dk

Abstract

In an effort to test the ability of a commercial grade EEG headset to effectively measure the N400 ERP, a replication study was conducted to see if similar results could be produced as that which used a medical grade EEG. Pictures of meaningful and meaningless hand postures were borrowed from the author of the replicated study and subjects were required to perform a semantic discrimination task. The N400 was detected indicating semantic processing of the meaningfulness of the hand postures. The results corroborate those of the replication study and support the use of some commercial grade EEG headsets for non-critical research applications.

1 Introduction

This study was designed to promote and validate the functionality of commercially available and user friendly neuroimaging technology as a brain-computer interface (BCI) and Electroencephalography (EEG) research tool. Developments in cognitive technologies are allowing researchers and users to access cognitive information in a cost effective manner. EEG is a measurement tool used to detect and measure the electrical signals in the brain when neurons communicate with each other. While invasive, cortically-implanted electrodes, allow for a more precise method of measuring brain activity, non-invasive scalp electrodes allow for a much more appropriate scientific method for the average researcher and user (Lin et al., 2008).

BCIs have shown an incredible ability to allow those with mobility disabilities to control medical devices such as prosthetic limbs (Nunez and Srinivasan, 2006; Guger et al., 1999; Müller-Putz and Pfurtscheller, 2008; Farwell and Donchin, 1988), wheelchairs (Barea et al., 2002a; Barea et al., 2002b; Rebsamen et al., 2006; Rebsamen et al., 2007; Barea et al., 2003; Chowdhury and Shakim, 2014) and robots (Neto et al., 2006; Chowdhury et al., 2014; Tripathy and Raheja, 2015). One reason this is possible is due to the ability to predict voluntary human movement more than a second before it occurs (Bai et al., 2011; Funase et al., 1999; Morash et al., 2008).

However, BCIs are not just used for mind controlled vehicles or devices using cognitive thought, they can also perform as diagnostic tools to detect driver fatigue (Zhao et al., 2011; Lin et al., 2008; Jap et al., 2009) and drowsiness (De Rosario et al., 2010; Khushaba et al., 2011; Lin et al., 2010; Eoh et al., 2005). This shows that applications using BCIs range from medical purposes for people who are locked in a vegetative state and helping them communicate with the world, to gaming/recreational purposes for healthy users who want to enhance their lives with smart technology.

While many EEG and BCI systems use medical grade technology as a data acquisition tool, the relatively cheap and wireless BCI system called the Emotiv EPOC is a cost effective consumer grade EEG unit with only 14 channels and this system has proven effective in several studies (Ousterhout and Dyrholm, 2013; Debener et al., 2012; De Vos et al., 2014a; Campbell et al., 2010; De Vos et al., 2014b). However the technology is still controversial as there are some studies that do not support its use fully (Duvinage et al., 2012; Stytsenko et al., 2011; Liu et al., 2012; Duvinage et al., 2013), stating that the system, being significantly worse than standard medical grade EEG, should only be used in noncritical applications. One noncritical application could certainly be communication.

When people communicate face-to-face, they typically engage in multimodal communication which simultaneously uses both modes of auditory and visual information. Auditory information normally only consists of speech, and visual information can include things like body behavior such as facial expressions, hand and arm gestures, and body posture. Visual information is also used inter alia to disambiguate context by providing supplemental information to the dominantly used vocal information, can be used instead of speech, and can change the meaning of speech (Goldin-Meadow, 1999; Kelly et al., 1999; McNeill, 2008; Kendon, 2004). While the auditory modality provides the most information content in face-to-face communication, thus typically being the dominant modality of communication, the visual cues are very important and sometimes necessary to understand fully what the intended message is (Clark, 1996).

Hand gesturing, for example, is an integral part of our daily communication paradigm. Hand gesture types can be categorized into several groups, while simultaneously being part of a larger continuum. For example, one type is called an emblem, which is a hand gesture requiring no verbal supplement, and has a conventionalized meaning in a particular culture, such as the thumbs up gesture in western cultures. These gestures can be useful in face-to-face communication because one gesture alone can give a complicated message to the recipient instantaneously (McNeill, 1992). Therefore emblems can be considered unspoken words or phrases, since there is a strong relationship between the gesture and it's meaning. Another type are iconic gestures, which are used to symbolize something, such as putting one's hands in the shape of a ball when talking about a ball. There are also deictic gestures, which comprise pointing hand postures.

Gestures thus contribute to the semantics of the dialogue in face-to-face communication. Semantics can be measured with EEG by looking at event-related potentials (ERPs), which are amplitude deflections in the brain produced in response to certain events or stimuli. One ERP has been studied for over thirty years to measure semantic processing (Kutas and Federmeier, 2011; Duncan et al., 2009; Kutas and Federmeier, 2000; Gunter and Bach, 2004) called the N400 ERP which is a negative deflecting component occurring 400 ms after the onset of a auditory or visual stimulus.

This ERP is used to measure semantic congruence. More specifically, the presence of an incongruous stimulus results in a much larger negative deflection than that of a congruous one, or one that is expected. Therefore, we can measure whether texts, images, or any other stimulus type are congruous or incongruous with the preceding context by looking at this ERP amplitude deflection. However, not all electrode positions measure this ERP since the responses to abstract words in semantic processing are typically found in centro-parietal sites, while concrete words, such as ones referring to picturable objects, have a frontal distribution (Holcomb et al., 1999).

The N400 has also shown utility in its ability to measure the amount of cognitive load required for an individual in semantic memory retrieval. This is because the ability to process the information from probe stimuli is highly dependent on one's ability to recall previous relevant stimuli from any of the multimodal channels such as images or sounds. This difficulty, or cognitive load, is associated with memory representations and cues from previous content priming the meaningful probe stimulus (Federmeier and Kutas, 2001; Lau et al., 2008; Van Petten and Luka, 2006). Therefore, when a difficult stimulus requires more effort to process, thus having more cognitive load, the N400's amplitude deflection is larger than when it is easy. It is therefore that the N400 is larger for rarely used words and when semantically incongruent or unrelated to previously acquired content (PETTEN, 1995; Laszlo and Federmeier, 2011).

A study done by Gunter and Bach (2004), investigated the N400 effect using pictures of semantically meaningful and meaningless hand postures. Pictures of 11 common and well-known emblematic, iconic, and deictic gestures were used as the meaningful stimuli along with 11 similarly positioned yet meaningless hand positions. The meaningful hand postures include things like ”thumbs up” and ”peace/victory” and other familiar postures which have a symbolic meaning to a given culture. During the pictorial semantic categorization task, subjects were required to identify, through a button press response, if each randomly displayed picture was meaningful or meaningless. They found that in comparison to mean-

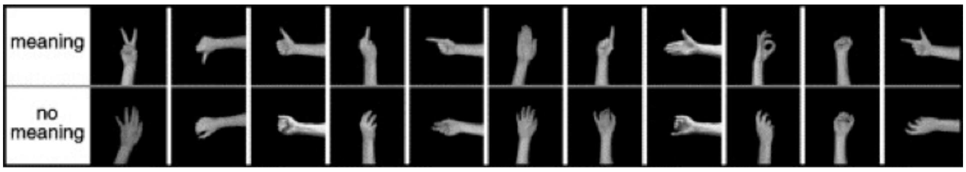

Figure 1: The 11 meaningful and similarly positioned yet meaningless hand postures provided by Gunter and Bach (2004).

ingful hand positions, the meaningless ones produced a larger negative going amplitude deflection in the centro-parietal region, which they classified as the N400.

This current study presumes to replicate precisely the study done by Gunter and Bach (2004) in an attempt to also find the N400, despite the fact that the Emotiv has no electrodes positioned that can measure the centro-parietal region which is where the N400 originates from. The hypothesis is that since the N400 is such a large ERP, even with the poor resolution of the 14-channel Emotiv, in comparison to the high resolution 59-channel medical grade EEG scalp cap used by Gunter and Bach (2004), the Emotiv will still be able to detect the N400 from the meaningless hand postures.

2 Method

2.1 Participants

This study used 16 participants who were native English or fluent English speaking adults at the University of Copenhagen. Their ages ranged from 20-37 years (mean = 26.9), 9 were males and all were right handed. All participants signed an informed consent form ensuring their understanding of the experiment to be conducted. All participants had normal or correct-to-normal vision with no reported psychiatric, neurological, or reading disorders that could disrupts this study's efficacy.

2.2 Stimuli

Participants were presented with stimuli courtesy of Gunter and Bach (2004) which consisted of 66 meaningful and 66 meaningless grey-scale hand posture photos. Each of the 11 meaningful and meaningless hand postures seen in Figure 1 were photographed by six different people and all 132 pictures were shown in 3 cycles.

2.3 Procedure

Using Paradigm stimulation software, which is a stimulus presentation software program that is good a millisecond display timing, a trial of the discrimination task progressed first with a random hand posture for 700 ms, then a blank screen for 500 ms, and finally a GO signal was presented indicating that the participant had to input with a button press if they judged the hand posture as meaningful or meaningless. This lasted approximately 20-25 minutes for each participant. Since the Emotiv is designed for real world applications, the study was done in a closed university office with normal lighting conditions and the possibility for auditory noise outside.

2.4 Electrophysiological Acquisition

For EEG acquisition, the 14-channel Emotiv was used which has electrodes at the International 10/20 system at AF3, F7, F3, FC5, T7, P7, O1,O2, P8, T8, FC6, F4, F8, AF4 with two left and right mastoid references at P3 and P4. The data was filtered offline from 0.1 to 30 HZ and sampled continuously at 128 HZ. To support the use of the Emotiv in the real world involving noisy environments in real time, no artifact rejection or correction was applied, however only correct responses were used. ERPs were identified and measured off-line using Matlab's ERPLab with a baseline averaged from the -200 to stimulus onset interval window and average ERPs lasted 1000 ms after the onset of the probe.

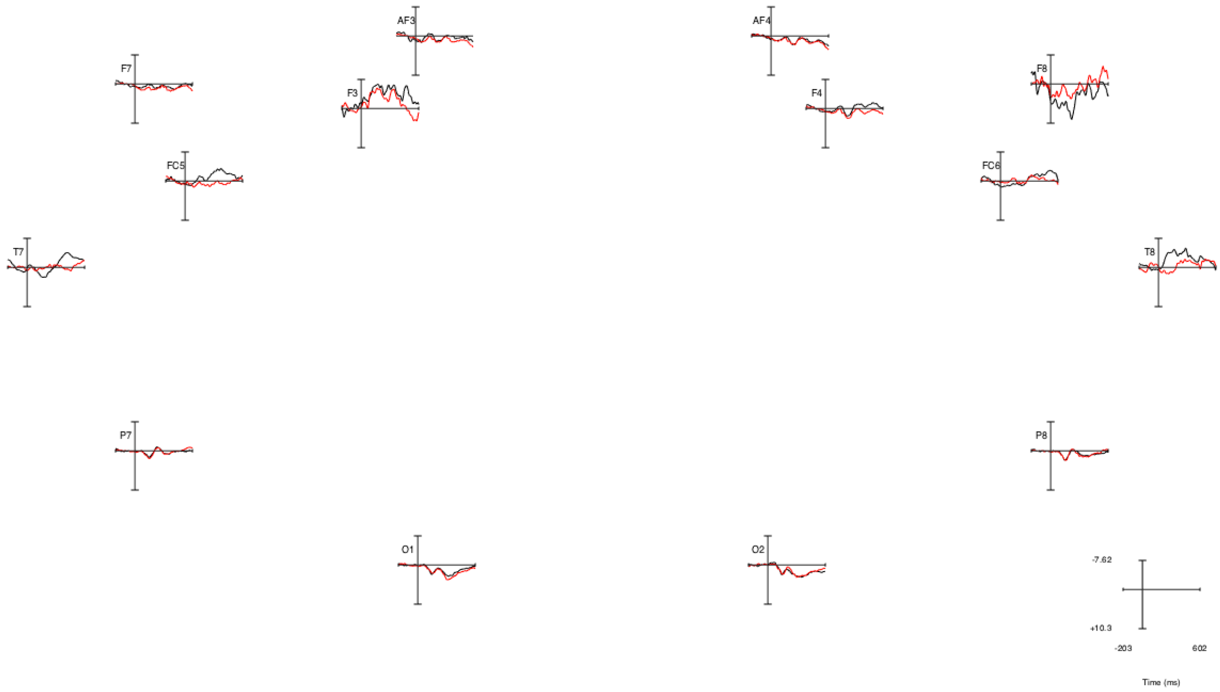

Figure 2: Wavelengths from the time window of -203 to 602 ms, where negativity is plotted upwards, and with congruous (red) and incongruous (black) conditions.

3 Results

3.1 Electrophysiological Results

The ERPs were measured using a repeated measures ANOVA with a 2 x 6 design (meaningfulness x electrode) using only the 6 electrodes F3, FC5, T7, T8, FC6 and F4 since they were closest to the PZ electrode position which is typically used to measure the N400. The mean amplitude for these 6 electrodes was calculated within the time window of 300-500 ms after stimulus onset. Figure 2 shows the grand average wavelengths of meaningful and meaningless stimuli and Figure 3 shows the scalp map distribution in the measurement time window in 50 ms intervals. The ANOVA Sphericity Assumed test showed an effect for meaningfulness ($F(1,15) = 5.36$, $p = 0.035$) and thus was identified as an N400.

4 Discussion

In summary, this study investigated the N400 effect regarding meaningless hand gestures compared to meaningful hand gestures made up of emblem, iconic, and deictic gestures. This study also replicated the paradigm and reproduced the results of Gunter and Bach (2004) regarding N400 detection. Most importantly, this study gives further evidence to support the use of a simple and affordable BCI as a research and user tool for noncritical EEG/ERP/BCI applications.

This study further corroborates with previous research regarding the issue of if some meaningful hand postures, such as emblems, are lexicalized and thus processed in the brain like words are. The theory was that since the comparison between meaningful words and similar yet false pseudo words produces an N400 effect, the same would go for meaningful hand gestures and similar yet false meaningless hand gestures. The increased N400 of the meaningless hand postures in comparison to the meaningful ones is similar to other studies (Bentin, 1986; Bentin et al., 1985).

The only difference between the result of this study and those done by Gunter and Bach (2004) are that there was an N300 effect with right-frontal distribution in that study which is indicative of picture processing and thus should have also been seen in this study (Barrett and Rugg, 1990; Federmeier and Kutas, 2001; McPherson and Holcomb, 1999; West and Holcomb, 2002). This current study found a greater negativity lateralized towards the left. The cause of this difference is unknown but will be investigated.

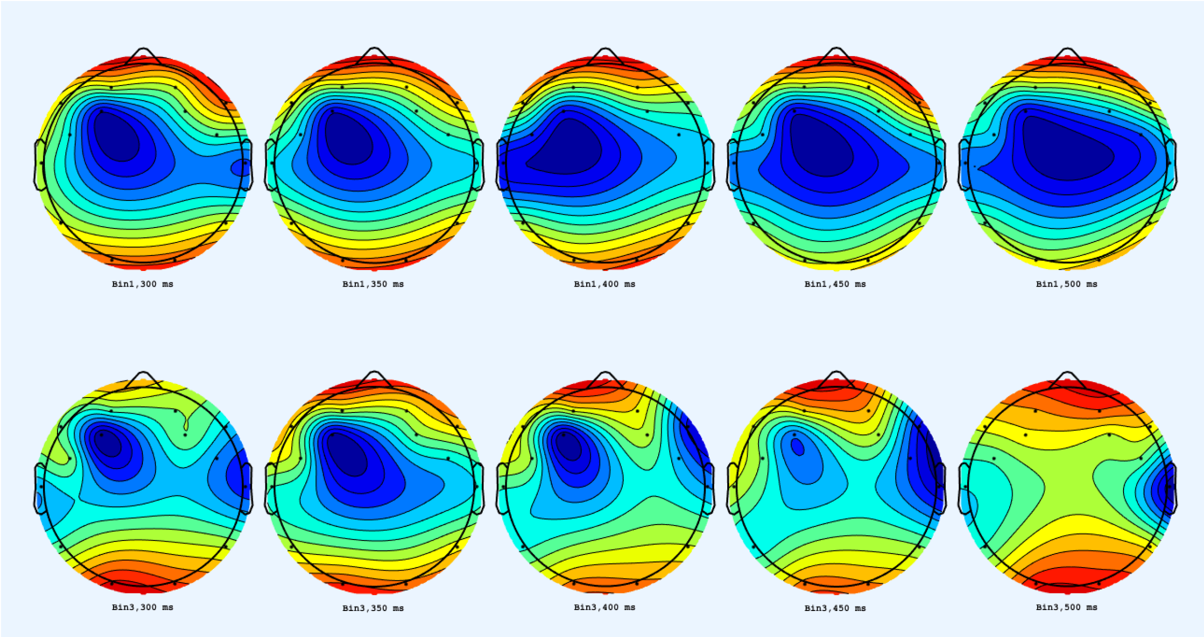

Figure 3: Scalp maps of incongruous (top) and congruous (bottom) conditions from 300 to 500 ms in 50 ms intervals.

However, Gunter and Bach (2004) did mention that the N300 and N400 effects were relatively small and could have been due to the large repetition of stimuli in the experiment and also could potentially have been facilitated with priming. Another potential explanation for the difference could be that Gunter and Bach (2004) used 22 native-German speaking students, where this study used 16 students from countries all over the world. This cultural difference could have had a dramatic effect on the semantic processing of the meaningful hand postures.

However, the most important part of this study is the demonstration that a simple, cost-effective, 14-channel EEG headset can detect the N400 in a similar manner that medical grade 59-channel EEG systems can. Even more impressive is that the system worked without any electrodes covering the source of the N400, and the data acquisition was done in a regular room with real world auditory and visual distractions, and no type of artifact rejection or correction was done. This further supports the usefulness of the commercially available EEG equipment, such as the Emotiv, as a research tool for ERP detection and user interface for BCIs.

5 Conclusions

This article demonstrated through a replication study of Gunter and Bach (2004) that the Emotiv headset, which is a relatively cheap commercial grade EEG acquisition device, can give results comparable to those of expensive high resolution medical grade equipment when measuring some ERP signals such as the N400. This is useful for a number of reasons. First, researchers and students can perform EEG experiments and contribute to the scientific world through published scholarly articles without the need of a medical environment and expensive equipment.

This also means that the rather exclusive field of EEG research can be easily accessed by virtually anyone allowing the volume of contribution to the field to increase dramatically. Furthermore, it can be assumed that the participants in the EEG experiments behave more naturally in an office than in an experimental laboratory and when they wear a simple EEG headset. Further research could be seeing what other areas the Emotiv is comparable to expensive EEG equipment or using the Emotiv for more semantic priming and N400 experiments.

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