Novel P300 BCI Interfaces to Directly Select Physical and Virtual Objects

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Abstract

We discuss two novel integrations of a brain-computer interface (BCI) to inform the wider BCI community of the possibilities presented by these applications. BCIs based on the P300 paradigm often use a flashing character or picture visual stimulus to elicit an event-related potential in the brain's EEG signal. Traditionally, P300-based BCI paradigms use a grid layout of visual targets (commonly an alphabet) and allow users to select representations of objects using their thoughts. First, we present a P300 BCI application that allows users to directly select 3D objects in a fully immersive virtual environment. Second, we discuss an application that allows users to select physical objects in the real world directly. This is done by using a multi-touch table that senses and highlights objects placed upon its surface by flashing an area of light around them. Both of these systems allows us to construct a P300-based BCI that uses a collection of objects as targets, rather than a pre-determined grid layout of representations of targets. Results show that our new paradigm works just as well as the traditional paradigm, thus highlighting the potential for BCIs to be integrated in a broader range of situations. This opens up the field of possibilities for the future of novel and integrated real-world P300 BCIs.

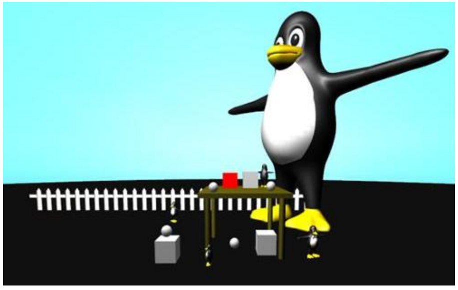
1 Introduction

A brain-computer interface (BCI) is a communication system where the user's commands "do not depend on the brain's normal output pathways of peripheral nerves and muscles" [1]. Thus, a BCI makes it possible to control a computer using only your thoughts. The most common form of BCI uses electroencephalography (EEG) as it is generally considered to be the least expensive and complicated method. BCIs can be used as communication channels for people with severe motor impairments such as amyotrophic lateral sclerosis (ALS). However, there is a growing interest in their use in more general applications [2].

We discuss two novel BCIs that highlight virtual or real objects directly. The opportunities that these two studies present are interesting and we feel they deserve to be widely read by the BCI community. The two studies employ EEG-based BCIs that use the P300 event-related potential (ERP). The P300 brain waveform is an ERP which denotes an increase in voltage of approximately 10μV, peaking around 300ms after the stimulus. It is triggered by an auditory, visual or somatosensory stimulus which is infrequent or particularly significant among other more routine stimuli. Its use for BCI was pioneered by Farwell and Donchin (1988) [3].

Previous P300-based BCIs have typically used a grid-based spelling task where a grid of flashing characters or symbols is displayed on a monitor. For example, even when navigating a virtual environment, the P300 grid has been used on a separate screen to allow interaction (e.g., [4], [5]). This means that users had to turn their heads away from the virtual space towards the P300 screen whenever they wished to interact with the virtual environment.

We present two of our own systems which allow users to interact directly with the target objects. The first study integrates the P300 BCI into a fully immersive virtual environment so



Standard Speller System	Multi-touch System
36 characters flashing.	36 object-blobs & non-objects flashing.
Select one character at a time.	Select one object at a time.
Spell 3-letter words x 4.	Select 3 objects x 4.

Figure 1: *Left*: A scene containing virtual object choices from [6]. A cube on the table (in red) is currently being flashed. *Right*: MTS and SSS experiment methodology comparison.

that 3D virtual objects can be selected directly [6]. The second study takes this one step further and demonstrates how physical objects can be used as P300 targets themselves [7].

The common thread running through both of these studies opens up the space of possible applications and consequent implications of P300-based BCIs. The future of the P300 BCI could be in the real and/or virtual world with direct, integrated user interaction.

2 Selecting Virtual Objects

Donnerer and Steed (2010) [6] demonstrated that it is possible to select virtual objects from a fully immersive virtual environment in a CAVE by using 3D objects as targets. Figure 1 shows the scene with different sized objects placed irregularly. Each object was randomly flashed one at a time, 8 times each. Instead of selecting a character or image from a regular grid, users selected the object itself by keeping a running mental count[1] when their target object flashed. Electrodes were placed at: Fz, Cz, P3, Pz, P4, PO7, Oz, PO8 based on the international 10-20 system and were connected to a g.MOBIlab+ 8 channel system. The P300 classifier was trained with g.tec software (16 flashes/character) using linear discriminant analysis.

Users were asked to select three different objects of varying difficulty based on their size and their proximity to neighbouring objects. Results were promising, with users being able to select objects with a total mean of 50% of the time. This mean includes the table object that was most difficult to select. Although there was no significant difference in accuracy between objects in the main trial, there were significant differences in the pilot studies.

3 Selecting Physical Objects

A possible next step following these promising results [6] was the ability to select real objects directly using a P300 based BCI. Therefore, we replaced the normal P300 grid of characters with physical objects [7].

We created a system whereby objects could be placed on a multi-touch surface which recognized the objects' outlines by a simple computer vision system. Image processing algorithms generated areas of light (object blobs) around these objects. We connected this multi-touch system (MTS) to the g.tec P300 based standard speller system (SSS). We customised the code in the g.tec software to intercept the control of the SSS and relay this over a UDP socket to the multi-touch table. Objects could then be flashed by surrounding the area underneath them with an area of light (figure 2). Users were then able to select any object on the table by keeping a running mental count of the number of times that object was flashed.

We compared the accuracy of the MTS with the industry standard P300 speller (SSS). We asked 20 participants to select four 3-letter words from the SSS and four sets of 3 objects from the MTS

[1] A running mental count is not necessary to trigger a P300 but is a convenient methodology.

Figure 2: A participant interacting with the multi-touch table P300-based BCI from [7]. Six objects have been placed on the table. Left: the spoon is flashed by surrounding it with light. Centre: A non-object flash. Right: the area around the CD is being flashed.

(figure 1 right). We used the same EEG parameters as [6]. Our participants had a mean accuracy rate of 96.2% using the SSS and 98.7% for the MTS. Our maximum bit-rate was 15.65 bits/min. We were also able to compare the overall success rates to another recent study by Edlinger et al. (2009) [4] who also used the same EEG parameters except with 15 flashes/character during trials. Table 1 shows the comparative accuracy results (Edlinger et al. do not publish bit-rate for the SSS so we cannot compare speed results).

4 Discussion

The two studies demonstrate that P300-based spellers can be used elsewhere in real and virtual worlds. For more general users, our main contribution is the first demonstration of a P300 BCI that does not use the standard speller or a simple graphic icon interface.

Results suggest that interfacing the P300 BCI with real-world objects works just as well as traditional paradigms and may even increase accuracy rates of target selection. Further studies would be required to isolate whether this increase in accuracy is due to the participant sample or some aspect of our system. However, we suspect a key difference is that we ran the experiment on a very fast multi-processor PC so that the 300ms delay in the brain response was precisely measured by the software. In addition, [4] used 15 flashes per object, whereas we used 8, thus fatigue may have been a factor in their study.

Another reason for our high classification accuracy of using real world objects may be due to the form of the interface (e.g., the multi-touch table being wide screen, or the object flashes being large areas of light). Participants did comment that it was easier to select larger cues, and this is also supported by [6]'s findings, suggesting that the size and shape of the cues are important. This would be an excellent topic for a follow-on study. Thus, these could be potential implications for the design of other P300-based BCI systems.

There are several direct applications for this new paradigm such as allowing "locked-in" persons to interact with real objects rather than a screen. For example, we could use more sophisticated computer vision techniques to recognize and label target objects in more general environments, breaking the limitations of a simple P300 screen with pictures or characters. The two studies together hint at a future scenario where real environments could be overlaid with augmented reality so that the physical objects could act as their own interfaces. In a smart home, a projector or array of lights could highlight objects to be used with the BCI. Alternatively, for the physical objects themselves to emit light rather than using a projector e.g., with LED lights integrated into the object. The active lighting can then be co-ordinated wirelessly to synchronize the flashes.

A more advanced option could be to wear a head-mounted or pendant-like mobile device with a camera and a small projector that augments the physical world and allows the user to interact with the world through BCI. This is not a far-fetched fantasy as a very similar device has already been created [8]. Their device uses a tiny projector and camera to visually augment surfaces, walls and physical objects. For example, they show a newspaper overlaid with live video news. Users do not have to wear goggles or glasses resulting in a direct and integrated user experience.

Classification Accuracy %	Edlinger et al. (2009) % of Sessions	Standard P300 Speller % of Sessions	Multi-touch BCI % of Sessions
100	55.3	70.0	90.0
80-100	76.3	95.0	100.0
60-79	10.6	5.0	0.0
40-59	7.9	0.0	0.0
20-39	2.6	0.0	0.0
0-19	2.6	0.0	0.0
Average Accuracy of All Subjects	82	96	99

Table 1: Comparison of classification accuracies of the P300 BCI in Edlinger et al. (2009) [4], the standard industry P300 speller, and the novel multi-touch table P300-based BCI in [7].

The interface of the Mistry et al. (2009) [8] device is based on hand gesture recognition. We suggest instead to use the P300 BCI as the interface: Object recognition algorithms could highlight potential objects in the scene from which to select, and additional virtual objects could be added to the scene to provide sufficent objects to trigger the P300 response. This future scenario is an integration of the two studies that we have presented here, whereby users can directly interact with physical and virtual objects together. Thus, as was highlighted as an important need in [2], this work opens up the space of opportunities for BCI.

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