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Towards an independent brain–computer interface using steady state visual evoked potentials

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Abstract

Objective: Brain–computer interface (BCI) systems using steady state visual evoked potentials (SSVEPs) have allowed healthy subjects to communicate. However, these systems may not work in severely disabled users because they may depend on gaze shifting. This study evaluates the hypothesis that overlapping stimuli can evoke changes in SSVEP activity sufficient to control a BCI. This would provide evidence that SSVEP BCIs could be used without shifting gaze.

Methods: Subjects viewed a display containing two images that each oscillated at a different frequency. Different conditions used overlapping or non-overlapping images to explore dependence on gaze function. Subjects were asked to direct attention to one or the other of these images during each of 12 one-minute runs.

Results: Half of the subjects produced differences in SSVEP activity elicited by overlapping stimuli that could support BCI control. In all remaining users, differences did exist at corresponding frequencies but were not strong enough to allow effective control.

Conclusions: The data demonstrate that SSVEP differences sufficient for BCI control may be elicited by selective attention to one of two overlapping stimuli. Thus, some SSVEP-based BCI approaches may not depend on gaze control. The nature and extent of any BCI's dependence on muscle activity is a function of many factors, including the display, task, environment, and user.

Significance: SSVEP BCIs might function in severely disabled users unable to reliably control gaze. Further research with these users is necessary to explore the optimal parameters of such a system and validate online performance in a home environment.

Keywords: BCI; BMI; EEG; ALS; Locked in syndrome; SSVEP; Attention; Dependent; Assistive communication

1. Introduction

Many people with motor disabilities cannot use conventional interfaces such as mice or keyboards. Although some of these users can use other interfaces such as eye trackers or EMG switches (Cook and Hussey, 2002), some severely disabled users require a means of communication that does not rely on motor control at all. Brain–computer interface (BCI) systems translate direct measures of brain activity into messages or commands. A variety of BCI systems have been described in the literature and typically are categorized according to the cognitive and neural activity needed for control (for review, see Kübler et al., 2001; Wolpaw et al., 2002; Allison, 2003; Kübler and Neumann, 2005; Jackson et al., 2006; Allison et al., 2007).

One type of BCI utilizes changes in steady state visual evoked potentials (SSVEPs). In this approach, a subject views one or more stimuli that each oscillate at a different constant frequency. When the subject focuses attention on

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one such stimulus, EEG activity may be detected over occipital areas at corresponding frequencies. Hence, an SSVEP BCI can infer user intent by measuring EEG activity at a specific frequency or frequencies over occipital areas. Although SSVEP BCIs work with healthy subjects (e.g., Middendorf et al., 2000; Cheng et al., 2002; Lalor et al., 2005) and subjects with moderate disabilities (Sutter, 1992[1]; Wang et al., 2004), they have not been validated with subjects unable to control gaze.

The prevailing view in the BCI literature is that SSVEP BCIs would not work in such subjects. SSVEP BCI articles typically note that subjects were told to shift gaze (Sutter, 1992; Middendorf et al., 2000; Cheng et al., 2002; Gao et al., 2003). Two BCI reviews (Kübler et al., 2001; Wolpaw et al., 2002) define SSVEP BCIs as "dependent" BCIs, meaning that they use EEG features that depend on muscle activity and thus would not work in patients without control over that activity. SSVEP BCI development would then be less important, as other assistive technologies based on gaze direction might be more effective (Cook and Hussey, 2002).

However, strong evidence from the visual attention literature suggests that people can shift attention among visual stimuli without shifting gaze. This phenomenon, called covert attention, has been verified in many human studies in which gaze shifting was carefully measured (e.g., Van Voorhis and Hillyard, 1977; Regan, 1989; Mangun and Buck, 1998; Golla et al., 2005). It has also been shown in SSVEP studies in which covert attention to an oscillating region or regions resulted in increased SSVEP activity at corresponding frequencies (Müller et al., 1998, 2003; Müller and Hillyard, 2000). These SSVEP studies were designed to rule out the possibility that results could be explained by shifting gaze. MEG work also shows that humans can produce changes in brain activity by attending to one of two overlapping images (Chen et al., 2003). Thus, an independent BCI based on covert attention may be a viable communication system even for users without gaze control.

The main goal of the study was to determine whether selective attention to one of two overlapping images would produce enough change in SSVEP activity to control an online BCI. This study compares an SSVEP display using non-overlapping checkerboxes to displays using overlapping stimuli. To determine whether color would help distinguish overlapping stimuli, two types of overlapping stimuli were used: colored and black/white (BW).

2. Methods and materials

2.1. Subjects

Subjects were 14 healthy adults (8 women, 6 men; age range 18–29 years, mean = 19.7, SD = 2.9), 11 of whom were undergraduate students at Georgia State University. All subjects were free of neurological or psychiatric disorders or medications known to adversely affect EEG recording. None had prior experience with EEG recording or BCIs. All subjects signed a consent form and earned credit in a psychology course or $10/hour for their participation. The nature and purpose of the study was explained to each subject before preparation for EEG recording. No subjects were excluded from the study nor chose not to participate. Everyone who asked to be a subject was a subject, and all data collected from these subjects are reported below. The study was reviewed and approved by the Georgia State University IRB.

2.2. Data collection

Subjects wore a 64-channel electrode cap (Electro-Cap International) using the International 10-20 system of electrode placement (Scharbrough et al., 1990). EEG channels were referenced to an electrode attached to the right earlobe, and a ground electrode was placed behind the right mastoid. All impedances were kept below 10 kΩ. Data were sampled at 160 Hz, band-pass filtered between 0.1 and 50 Hz, and amplified 20,000× on an SA Instruments biosignal amplifier. The BCI2000 software package (Schalk et al., 2004) was used for all data acquisition. Stimuli were presented using Presentation (Neurobehavioral Systems) and analyzed using BCI2ASCII (Wadsworth Center) and Matlab Release 12 (Mathworks). Data were collected in a busy office area with occasional uncontrolled distractions, rather than a shielded room, as this represents a more realistic environment for BCI use.

2.3. Display and procedure

After being prepared for EEG recording, subjects were seated in a comfortable leather chair about 3 ft from a 21″ ViewSonic CRT monitor with a 60 Hz refresh rate. In all conditions, subjects viewed two images that each oscillated at a different frequency (see below). All subjects participated in 12 one-minute runs that were separated by breaks of 30–60 s (see Table 1). Subjects completed questionnaires after the last run.

Fig. 1 illustrates the images used in the three conditions. For half the subjects, the first eight runs involved spatially overlapping images called "lineboxes" that each consisted of parallel vertical or horizontal lines against a black background (Chen et al., 2003). During these runs, the two images appeared at the same location in the center of the monitor. All lineboxes were about 8.5 in. tall by 8 in. wide and subtended about 10° of user-centered space. The image containing horizontal lines oscillated at 10 Hz, and the image containing vertical lines oscillated at 12 Hz. This was achieved by presenting each image for two frames followed by either three or four frames without that image. During frames in which both images appeared, an image that represented the superposition of both images was

[1] Sutter's approach uses m-sequence encoding, which is not a steady state stimulus and does not produce a classic steady state response. However, his 1992 article is typically grouped with SSVEP BCIs since this approach is somewhat similar.