Towards a Gaze-Independent Hybrid-BCI based on SSVEPs, Alpha-Band Modulations and the P300

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Abstract— In recent years it has been shown to be possible to create a Brain Computer Interface (BCI) using non-invasive electroencephalographic (EEG) measurements of covert visual spatial attention. For example, that both Steady-State Visual Evoked Potentials (SSVEP) and parieto-occipital alpha band activity have been shown to be sensitive to covert attention and this has been exploited to provide simple communication control without the need for any physical movement. In this study, potential improvements in the speed and accuracy of such a BCI are investigated by exploring the possibility of incorporating a P300 task into an SSVEP covert attention paradigm. Should this be possible it would pave the way for a gaze-independent hybrid BCI based on three somewhat independent EEG signals. Within a well-established SSVEP-based attention paradigm we show that it is possible to make a binary classification of covert attention using just the P300 with an average accuracy of 71% across three subjects. We also validate previously published research by showing robust attention effects on the SSVEP and alpha band activity within this paradigm. In future work, it is hoped that by integrating the three signals into a hybrid BCI a significant improvement in performance will be forthcoming leading to an easily usable real time communication device for patients with severe disabilities such as Locked-In Syndrome (LIS).

I   INTRODUCTION

A brain–computer interface (BCI) may be the only feasible channel for communication in people with very severe disabilities (e.g., amyotrophic lateral sclerosis or brainstem stroke), [1]. One attractive technology for implementing BCIs is electroencephalography (EEG), given that it is noninvasive, relatively inexpensive, widely available, easily portable and relatively easy to use. Existing EEG-based BCI designs rely on a variety of EEG signal features, e.g., slow cortical potentials [2],

oscillatory activity [3], P300 potentials [4], and steady-state visual evoked potentials (SSVEPs) [5].

Recent research has sought to improve BCI performance by combining several EEG signal features to create a, so-called, hybrid-BCI [6,7]. The rationale is that, by designing a paradigm that facilitates the simultaneous control of several somewhat independent EEG features, one can combine these features to give a BCI performance that is better than any individual feature. Designing such a paradigm must allow for usability on the part of the subject.

One important consideration for BCI paradigms is whether or not the intended user retains control of eye movement. If so, then the user can make selections by shifting gaze direction – an ability that may, however, be more efficiently measured using an eye-tracking system. If not, then any appropriate BCI paradigm must be independent of eye-gaze. Several studies have concentrated on the design of such eye-gaze independent BCIs with many exploiting the fact that covert visual attention can produce changes in easily measured EEG features [8]. These include BCIs based on covert attention to stimuli capable of producing ERPs (including those with P300 components) [9-14] and those designed to elicit SSVEPs [15].

The fact that both P300s and SSVEPs have been shown to be viable EEG features within the context of a gaze-independent BCI suggests that they could be combined to produce a gaze-independent hybrid-BCI with potentially better performance. Indeed some researchers have already considered this combination of EEG features in the context of BCIs that allow eye-movement [6,16-18]. Here we seek to investigate the possibility of incorporating a P300 paradigm into an established gaze-independent SSVEP-based BCI design [15,19]. Indeed this previously published SSVEP-based BCI can already be considered a hybrid-BCI given that it combines somewhat independent measures of attention on both SSVEPs and parieto-occipital alpha band activity. Should it be shown to be possible to classify attention based on the P300 in this paradigm, then it should be possible to combine all three features to produce improved BCI performance.

II   METHODS

A. Subjects

3 subjects participated in the study (two female;

aged 22–32 yr), all of whom were right-handed and had normal hearing. All had normal or corrected-to-normal vision.

B. Experimental Setup

Subjects were seated 60cm from a CRT monitor on which was displayed two white rectangular flicker stimuli situated 2.9° bilateral to a central fixation cross on a black background, as shown in Fig. 1. The refresh rate of the monitor was set at 60Hz. The boxes were set to flicker at a rate outside of the alpha band so that alpha band modulations could also be used during classification [15]. The left rectangle flickered at 15Hz and the right at 20Hz.

Event-related potential (ERP) studies examining the static allocation of visual spatial attention normally involve the task of target detection. In the centre of each of the white rectangles (4.2x4.2° of visual angle), letters from "A" through "H" (1x1°) were presented in a random pattern, similar to the paradigm employed in [15]. Embedded in the sequence of letters was the target letter "C", occurring with equal probability (~0.11). Subjects were instructed to keep count of target presentations during each trial and report this number by mouse click on completion of the trial. This provided a behavioral measure of spatial attention performance. The letter in each rectangle was changed after 3 flashes of the rectangle on which it was superimposed. To facilitate the comparison of discrete ERP responses to Cs in the attended and unattended hemifield, there was a minimum of 1 sec between the occurrence of any C stimulus.

Continuous EEG signals were recorded from 128 electrode positions, filtered over the range 0– 134 Hz and digitized at a rate of 512Hz using the BioSemi Active Two system.
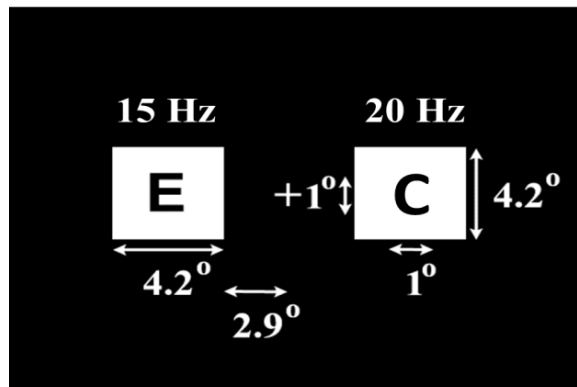

Fig. 1. Stimulus Display

C. Procedure

Each subject underwent a total of three blocks, each lasting approx. 10 minutes. Each block contained 20 trials. Each trial started with a red warning stimulus lasting 0.5s, followed by a cue stimulus consisting of a white fixation cross of the same size with an arrow on the left or right arm, lasting 0.5s. Depending on the direction of the arrow, the subject was instructed to covertly attend to the left or right rectangle while strictly maintaining fixation on the central fixation cross for 20s. Following the attend period a green fixation cross was presented for 5s, signifying a rest period. Each session consisted of 20 trials, with an equal number cued-left as cued-right, in random order.

An SR Research Eyelink eye tracker (EyeLink version 2.04, SR Research Ltd/SMI) recorded eye movements. If a participant blinked or moved their eyes > 3.5° from fixation during the trial period, the trial was restarted.

III   ANALYSIS METHODS

A. P300 Feature Extraction and Classification

For each subject, raw EEG data were first low-pass filtered to 8Hz, re-referenced to the average reference, then epoched relative to the onset of Cs in both the attended and unattended hemifield (-250ms to 1000ms). Epochs were then baseline corrected with respect to a 250 ms prior to the onset of the C. For each 20 s trial, epochs to attended and unattended epochs were averaged separately.

A simple classifier was used to discriminate whether subjects were paying attention to the left or right hemifield. Amplitude from a time window of 350ms – 650ms in the averaged epochs was taken from the electrode CPz for the attended and unattended hemifield. A hemifield was classified as being attended to if there was greater amplitude to Cs appearing in that hemifield.

B. SSVEP Feature Extraction

The raw EEG data of Subject 2 were low-pass filtered to 40Hz, re-referenced to the average reference and epoched relative to onset of each 20s trial. To show the effect of attention on the SSVEP, the power spectrum of each trial was plotted from the occipital electrode Oz. This allowed a comparison of power in the respective frequencies for each hemifield (15Hz in the left, 20Hz in the right).

C. Alpha band Feature Extraction

Raw EEG data from Subject 2 underwent the same process as detailed above in the SSVEP analysis. In order to demonstrate the presence of alpha band (8 – 14Hz) modulations by attention, power in the alpha band was plotted for attend and unattend conditions

separately for each hemifield. For each 20 second trial, the power spectrum was plotted from two electrodes commonly used when measuring effects of spatial attention on alpha power, PO7 over the left hemisphere and PO8 over the right hemisphere [19]. Alpha power was then compared in each hemisphere, for attend left versus attend right.

IV   RESULTS

Fig. 2 shows the grand mean ERPs elicited for attend and unattend conditions, averaged together for left and right hemifields. A clear positivity can be seen for the attend condition, peaking at approx. 500ms, in line with P300 morphology. Interestingly however, it does appear quite late for the P300, which is typically between 300 and 400ms for sudden onset stimuli [20].
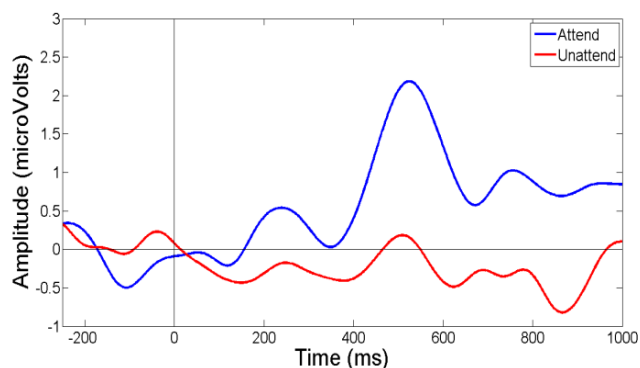

Fig.2. ERPs elicited for attend and unattend conditions, demonstrating the P300 effect (blue line) peaking at approx. 500ms.

Classification accuracy for each subject can be seen in Table I, with a mean accuracy of 70% for the group. All subjects attained a statistically significant level of performance ($p < 0.05$), measured using the binomial probability method.

TABLE I
CLASSIFICATION ACCURACIES FOR ALL SUBJECTS OVER ALL SESSIONS USING THE P300 FEATURE ALONE.

Subject	Attend Left (%)	Attend Right (%)	Mean Acc. (%)
1	82%	67%	74%
2	58%	75%	67%
3	73%	61%	68%
MEAN	**71%**	**68%**	**70%**

The other features of the paradigm remained sensitive to attention. Occipital alpha power was influenced by attention, with greater alpha power ipsilateral to the attended side, as seen in Fig. 3. The SSVEP was also found to be modulated by attention such that there was greater power at the SSVEP frequency corresponding to the attended hemifield (Fig. 4). This effect was much greater in the 15Hz peak for the left hemifield, although the effect was still present in the 20Hz peak.

IV   DISCUSSION

We have shown it is possible to classify the allocation of attention to the left or right hemifield of visual space using the P300 response within a paradigm that is known to elicit attention effects on both SSVEPs and parieto-occipital alpha band activity. This is an important step forward in BCI technology, as it has been suggested [21] that a P300 based paradigm may be reliant on eye gaze. The present paradigm prevented the participant from making overt eye movements to focus on the peripheral letter streams yet still demonstrated P300 activity robust enough to correctly classify attentional allocation well above chance levels for all subjects. Furthermore, it was demonstrated that other measures such as the attentional modulation of SSVEP and alpha band power remain.
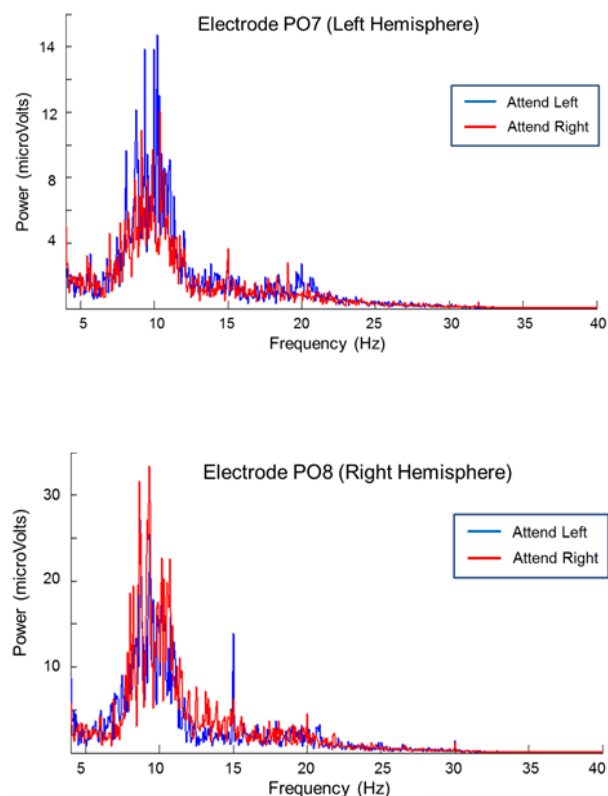

Fig.3. Modulation of occipital alpha power by attention, showing greater ipsilateral compared to contralateral alpha power for the attended side.
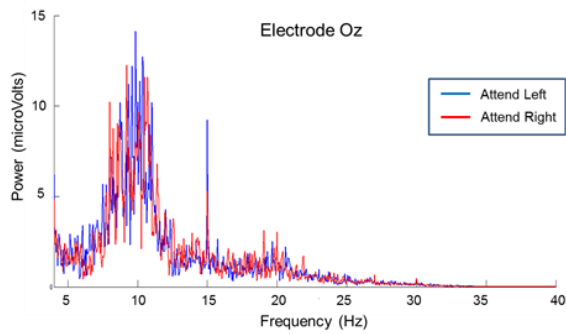
Fig.4. Modulation of the SSVEP feature by attention, evident at 15Hz (left hemifield), and to a lesser extent, 20Hz (right hemifield).

Future work with more subjects will combine P300 measures attained here with the SSVEP and alpha power measures gained previously [15, 19] and investigate their mutual independence. Kelly et al. showed some independence between alpha and SSVEP showing that combining them was better than using either of them alone [15]. Given that the neural generators of the P300 [20] are distinct from those of both the SSVEP [22] and alpha [23], we anticipate a high degree of independence between these measures.

V   CONCLUSION

Utilizing solely the P300 measure to peripheral targets in a covert attention paradigm, correct classification of attended hemifield can be made with an average accuracy of 70%. Combination of this measure with other BCI measures such as SSVEP and alpha power modulation should enhance overall classification accuracy, leading to a more efficient BCI that is entirely independent of motor movement.

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