Alpha Band Activity during Eye-Closure in People with Spinal Cord Injury

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Introduction

Brain-Computer Interfaces (BCIs) offer a potential "hands-free" command interface for neuroprostheses in people with spinal cord injury (SCI), using signals arising directly from the brain. However, for convenience BCI development is usually conducted with able-bodied subjects. In order to optimize performance for persons with SCI we need to know the impact the injury has on brain signals used by BCIs.

We have developed a BCI based on reactivity of electroencephalogram (EEG) activity in the alpha band (8-13 Hz) due to eye-closure [1]. The ability of able-bodied persons and individuals with SCI to operate an environmental control system (ECS) using the BCI was recently demonstrated [2]. The BCI has also been demonstrated to be an effective command interface for a hand-grasp neuroprosthesis [3]. Using the current design, able-bodied subjects can generally activate the BCI faster than SCI subjects [2]. A preliminary study, collecting data from occipital sites, identified differences in alpha band frequency and amplitude between 20 SCI and 16 able-bodied subjects [4]. Subjects with SCI had lower alpha-band frequencies and peak amplitudes compared to able-bodied subjects. There is still a lack of information concerning the influence of SCI on EEG activity over the entire cortex. The purpose of this study is to examine the impact of SCI on alpha band activity over the whole cortex, during eye-closure.

Methods

Participants

Two groups participated in this research, including 20 SCI and 20 able-bodied subjects. The controls were individually matched to the SCI group for age and sex. The SCI group consisted of 18 males and 2 females, with a mean age of 34.3 years (SD=10.6 years). The able-bodied group consisted of 18 males and 2 females, with a mean age of 33.7 years (SD=11.2 years). SCI participants were approached for their willingness and informed consent to participate in the study when they were patients in a rehabilitation ward. Eight of the persons with SCI had tetraplegia (C5-C7 levels) and the remaining 12 were paraplegic (T4-T12 levels). All subjects with SCI had complete lesions. The able-bodied subjects were selected from hospital and university staff. All able-bodied participants were matched to the SCI group on a case by case basis for sex and age (± 5 years). Exclusion criteria for entry included a history of traumatic brain injury and non-English speaking.

EEG procedure

Data was recorded from 52 electrodes with an ActiveOne data acquisition system from Biosemi (www.biosemi.com). However, only 14 channels were used in the study reported in this paper. The channels corresponded to sites from the International 10-20 electrode system Fp1, Fp2, F3, F4, Fz, C3, C4, P3, P4, T5, T6, Pz, O1, and O2. All channels were referenced to Cz. Skin preparation was performed on each electrode site to reduce the impedance below 10k-ohm. Signals were filtered to a bandwidth of DC - 500 Hz, and sampled at 2048 Hz.

In-house software was written in Labview (version 6.1, National Instruments) to automatically prompt the subject and record EEG data. Subjects were instructed to follow audio prompts from the computer speaker. The program initially recorded 5 seconds of preliminary data (later discarded), and then presented audio prompts to the subject of "close your eyes" and "open your eyes", alternating at 20 second intervals. Subjects were asked to keep their gaze toward the screen when their eyes were open. Three intervals each of eyes-closed and eyes-open data were collected and saved to disk. The EEG data record was marked at the beginning of each audio prompt to aid post-analysis.

Post-processing software, written in Labview, selected data from the three eyes-closed intervals. The first 2 seconds of each interval were discarded to ensure data corresponded to an eyes-closed state. The remaining 18 seconds of each interval were subdivided into 2-second epochs, which were multiplied by a 4-term Blackman-Harris window, and transformed with an FFT to calculate the magnitude spectrum. Alpha-band (8-13 Hz) and broadband (3-30 Hz) magnitudes were calculated as the sum of the components in the FFT for the corresponding frequency range, and were averaged over all epochs in a trial. These were further averaged over the 3 trials. Peak amplitude was calculated as the maximum FFT component in the alpha band among all epochs in a trial, and averaged over all trials. Peak frequency was calculated as the frequency of peak amplitude, and averaged over all trials.

Statistical analysis

Differences in alpha-band magnitude, peak amplitude and frequency between groups were tested using analysis of variance (ANOVA). Testing for differences between the tetraplegic and paraplegic sub-groups was conducted using Mann-Whitney U Test due to the lower numbers involved. Because of the large number of ANOVA's needed to be performed between the two groups and between the SCI sub-groups, the Type I error was potentially high. Therefore, an alternative method based upon directions of difference was also used in order to indicate the consistency and direction of differences between groups. The Sign Test was used to determine the probability that the SCI group would always be lower than the EEG values of the able-bodied group. A value of 0.5 was therefore given to each prediction of difference for all 14 sites between the two groups, since there is theoretically a 1 in 2 probability of the SCI group being greater or lower than the able-bodied group EEG values. A value of 1 would be given to each incorrect prediction (that is, SCI EEG value was actually greater than the able-bodied group). Using this technique, the probability of finding valid and consistent differences in a specified direction in the 14 sites can be estimated in contrast to chance findings.

Results

Statistics for alpha-band magnitude, peak amplitude and frequency are shown in table 1.

Alpha-band magnitude differences

The Sign Test showed the SCI group had lower alpha-band magnitudes than the able-bodied group in all 14 sites. These differences become greater in posterior sites. The Sign Test suggests the probability of all 14 able-bodied sites having greater magnitudes by chance is almost 1 in 17,000 (that is, $(0.5)^{14} = 0.00006$).

Peak amplitude differences

Although there were few significant differences between the two groups, the Sign Test showed a consistent reduction in peak amplitudes in the SCI group for all 14 sites. There were greater differences in peak amplitude found between the two groups at posterior and central sites. Again, the probability of all 14 sites showing lower SCI values by chance is 1 in almost 17,000.

Peak frequency differences

There were greater differences in peak frequencies found between the two groups at posterior and central sites. Although there were few significant differences between the two groups, there was a consistent reduction in frequency in the SCI group for 13 sites (all sites except F3). Again, the probability of this happening by chance is 1 in almost 10,000 (that is, $(0.5)^{13}= 0.0001$).

Table 1. Statistics for Magnitude, Peak Amplitude, and Frequency ± Standard Deviation in the alpha-band for subjects with SCI, including F values and significance of comparisons to the able-bodied group.

Site	Magnitude (uV)	F	Peak Amplitude (uV)	F	Frequency (Hz)	F
FP1	14.4±4.3	2.9	5.0±2.1	2.0	9.2±0.9	0.2
FP2	14.2±4.2	3.1	4.9±2.1	2.2	9.4±1.0	0.1
F3	10.9±3.9	3.0	3.8±1.7	2.7	9.5±1.0	0.0
FZ	10.1±3.8	2.2	3.7±1.7	2.1	9.2±1.0	0.9
F4	10.8±3.7	2.8	3.9±1.7	1.9	9.3±0.9	0.8
C3	10.2±4.4	2.5	3.3±1.7	2.7	9.3±1.0	1.5
C4	9.9±4.7	2.5	3.3±1.8	1.8	9.4±1.1	1.6
T5	24.2±10.7	2.1	8.7±4.5	2.0	9.3±0.9	2.4
P3	20.2±10.4	0.3	7.3±4.1	0.5	9.4±1.0	4.5*
PZ	14.4±8.2	2.6	5.5±3.5	2.6	9.4±1.0	4.1*
P4	19.2±9.9	3.1	6.9±3.9	3.2	9.4±1.0	4.2*
T6	23.9±10.4	4.4*	8.7±4.4	3.6	9.3±0.9	5.5*
O1	28.3±13.8	3.6	10.3±5.8	3.9	9.4±0.9	5.6*
O2	27.7±12.9	5.9*	10.2±5.8	5.4*	9.5±0.8	8.4#

* $p<.05$ # $p<.01$

Differences between the paraplegic and tetraplegic sub-groups and the controls

While no significant differences were found between the paraplegic sub-group and the able-bodied controls, differences were still in the predicted direction. The tetraplegic groups alpha-band magnitude (p=0.00006), peak amplitude (p=0.00006) and frequencies (p=0.0001) were consistently lower than those of the able-bodied group, and many reached statistical significance in the posterior, central and temporal sites. A comparison of alpha-band magnitude at occipital site O1, between able-bodied, SCI (combined), and tetraplegic groups is shown in Figure 1. The group with tetraplegia also had consistent and significantly lower alpha-band magnitudes and peak amplitudes than the paraplegic sub-group, however, there were no significant differences in frequencies between the SCI sub-groups.

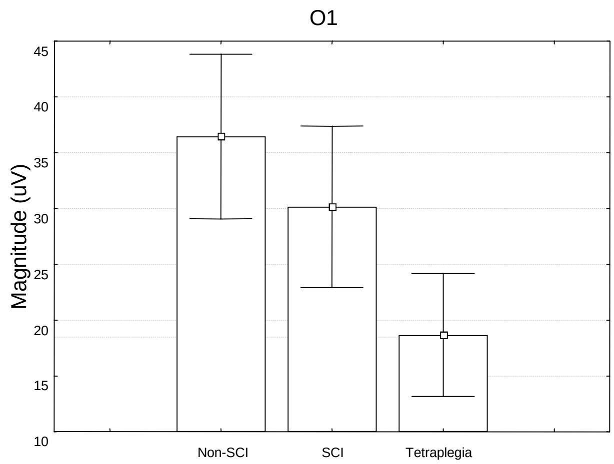

Figure 1. Comparison of alpha-band magnitude at occipital site O1, between able-bodied, SCI (combined), and tetraplegic groups

Discussion

The aim of this research was to investigate the influence of SCI on alpha-band activity. It was believed important to examine the EEG activity in the SCI group for two reasons: (i) little is known about the effect of SCI on EEG, (ii) the information will help improve performance of BCIs based on eye-closure operating neuroprostheses in SCI persons. The results of the paper were similar to those found in the preliminary study as there were significant differences found between the SCI group and able-bodied group in terms of alpha-band magnitude, peak amplitude and frequency in the posterior sites [4]. When the SCI groups were broken down further to sub-groups (paraplegic and tetraplegic) significant reductions in brain activity were found in central, temporal and posterior cortical sites in the sub-group with tetraplegia. There were no significant differences found between the able-bodied group and the paraplegic group. This difference between sub-groups is likely the result of a greater reduction in afferent input in the tetraplegic sub-group. There were no significant differences in the frontal regions between any of the groups. The lack of significant differences may reflect the sample power in this study. If say, the number of participants were doubled then significant differences between the SCI group and able-bodied group would have substantially increased.

It is important to note the direction of difference over all 14 sites, with SCI EEG values almost always lower than values for the able-bodied group. This suggests that deafferentation influences alpha-band activity over the whole cortex, particularly for individuals with tetraplegia. The presence of alpha-band activity is usually associated as an indicator of cortical deactivation. However, the reduction of activity was not limited to the 8-13Hz spectrum of the EEG. While not reported in this paper, we found consistently lower EEG activity in the SCI group across the broad EEG spectrum (3-30Hz). The overall reduction of brain activity in SCI compared to able-bodied subjects is therefore best understood as being due to an overall loss of afferent pathways. Furthermore, these reductions in brain wave activity are unlikely to be the result of drugs commonly administered during rehabilitation such as anti-spasmodics (eg. Baclofen) and anti-depressants, as these drugs were more likely to increase alpha-band activity rather than reduce it [5].

Despite less alpha-band magnitude and peak amplitude in SCI participants compared to able-bodied participants the level of alpha-band activity found in the SCI groups was still substantial enough for successful operation of BCIs using eye-closure.

References

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