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Correlation of EEG Band Power and Hand Motion Trajectory

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Abstract

A preliminary analysis of the correlation between high resolution EEG and three dimensional (3D) hand motion trajectories is presented. The study involved assessing which EEG frequency components and cortical areas show the most significant correlation with hand motion trajectory towards five targets positioned in different locations in space. The time shift between time-power pattern of the selected EEG frequency and related motion trajectory is also analyzed. The results show strong correlation between EEG and kinetic data in low frequency (0.5-4Hz) range as well as significant correlations in the 28-36Hz range. The results indicate that these EEG frequency bands may best be used to develop an EEG-based brain-computer interface (BCI) for the decoding of 3D hand motion trajectories.

1 Introduction

Motion trajectory prediction based BCIs aim to exploit the relationship or correlates between EEG signals and limb motion to decode an imaginary limb movement in 3D space. To date only a limited number of studies have investigated EEG and kinetic data associated with 3D limb movements [1], [2]. Studies have shown that band-pass filtered low frequency EEG components around 2Hz convey a lot of information to the decoding task. Although Antelis et al [3] have drawn attention to possible misinterpretation of the results when using low frequency based motion prediction models, Paek et al. [4] have recently demonstrated the feasibility of decoding finger kinematics from low frequency scalp EEG signals. To date a comprehensive assessment of the spatial and spectral EEG correlates of real and imagined 3D hand motion trajectory has not been conducted. This paper aims to address this with an analysis of subjects undergoing a high resolution EEG recording whilst performing real and imagined 3D hand movements towards five targets positioned in different location in space. Sub-bands in the 0.5-40Hz EEG spectrum which show the highest level of correlation with movement trajectory are identified. The correlation strength of different cortical areas and different phase shifts between EEG and kinetic records are also assessed to learn more about the relationship between EEG signals and kinetic data.

2 Experimental Task and Data Collection

The experimental task involved moving the right dominant hand between a home position ("H") and one of five target positions and return to home position. Target 1, 2 and 3 lie in the shoulder plane forming 45°, 67.5° and 90°, respectively, between the torso and the shoulder. Target 4 and 5 lie 45°

below and above the shoulder plane, forming 90° between the torso and the shoulder. Real movement blocks to a particular target were followed by imagined movement blocks to the same target. Participants could choose a home position that varies between subjects and blocks. Figure 1 illustrates motion trajectories of Subject 1. The task cue was synchronized with an auditory signal. Movements were followed by a rest phase. Both fast movements and slow movement blocks were interleaved where the length of motion and rest phases was 800ms and 500ms for slow and fast movement, e.g., Block 1 – movement H → 1 → 1 → H →H (0.8s each). The duration of the blocks was 48s, with an approximate inter-block interval (IBI) of 30s. The number of registered blocks was 20 from which only ten were considered in this study (slow and fast real movements between home and target positions). The analysis of the imagined movement blocks will be the subject of future study. Datasets containing parallel registered Electroencephalogram (EEG), Electromyogram (EMG) and kinetics data were acquired from six healthy right handed male human subjects (age range 25-42 years). EEG signals were registered in 62 channels + 1 electro-oculogram (EOG) at 1200 Hz. EMG was recorded from the Biceps with a sample rate of 2000Hz. Kinetic data were recorded from the right dominant hand, elbow and shoulder at 30 frame per seconds (FPS) using a 3D Microsoft Kinect camera system. All datasets were acquired at the Hybrid BCI lab at Holon Institute of Technology (HIT), Israel.

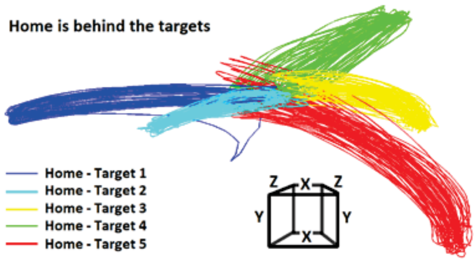

Figure 1: Hand motion trajectories of Subject1. This figure is prepared by smooth filtered, valid kinetic data.

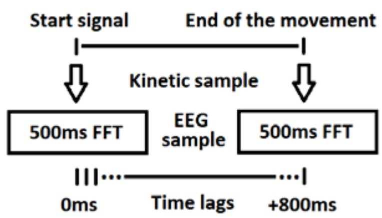

Figure 2: Illustration of synchronization between FFT windows and kinetic data in case of slow tasks.

3 Preprocessing

EEG and kinetic data were stored in a pointer based structure that enabled variable length of epochs without re-slicing and reduced memory requirement. Baseline shift was removed and the EEG was filtered by 0.5-40Hz, eight-order, band-pass Butterworth filter. The Fast Fourier Transformation (FFT) was applied for calculating power value of EEG frequency components in 2Hz wide bands (non-overlapped) between 0 and 40 Hz. We used 500ms width FFT windows and 33.3ms time lags between two windows. This lag has been chosen for ease of synchronization with kinetic data sampled at 30FPS. Figure 2 illustrates the setup of FFT window for slow tasks i.e., 800ms. Smoothing filter has been applied on kinetics data for noise reduction as the band-pass filtering causes a distortion in data at the beginning of motion. The filter calculated a mean value of five adjacent samples.

Time synchronization is crucial in this comparative analysis. We used the sample rate converted EEG triggers for synchronizing the kinetic data with the EEG data where the first trigger was recorded simultaneously for both data types. Task compliance validation was performed manually. Tasks were considered valid only when converted EEG triggers matched the beginning of the motion. Subject 6 was discarded due to inadequate kinetic records.

4 Correlation Analysis

The correlation coefficient between a power pattern (belonging to one of the computed FFT frequencies) and related kinetic data was calculated for each valid trial.

The kinetic data consist of an x, y or z Cartesian vector component of hand coordinates in the 3D space or joint angle at the elbow, hand and shoulder reference points. We analyzed the correlation between the two descriptors during the movement hence the size of the correlation window matched the time interval of the related task (slow tasks 800ms, fast tasks 500ms). Pearson's linear correlation was chosen as we were interested in the correlation strength between two row vectors. The first row vector contained EEG band power values which were gained from FFT at analyzed time lags, the second one contained the kinetic data (see Figure 2). The *corrcoef()* Matlab function was used for computation of correlation coefficients (*R)* and *p* values from Student's t-test. The most significant *R* values were used for further analysis ($p<0.01$). As we were only interested in the correlation strength between the two descriptors, the correlation sign was overlooked.

We also aimed at detecting the time shift between EEG and kinetic record wherein correlation is maximal. Therefore, we repeated the above calculations for different time shifts between EEG and kinetic patterns. Figure 3 summarizes the distribution of correlation level between the EEG signal and related Hand(z) trajectory, where the vertical axis represents the different EEG frequencies and the horizontal axis represents the time shifts between EEG signal and kinetic record. (e.g., the -200ms column contains correlation intensity for an EEG compared with kinetic data registered 200ms earlier which is an already executed motion thus the +200ms column compares EEG and planned motion). Colour code indicates strength of the correlation where red colour denotes higher correlation levels.

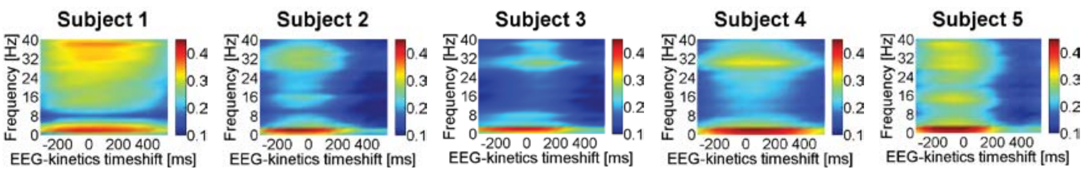

Figure 3: Correlation level distribution between EEG patterns and Hand(z) trajectories for different EEG frequencies and time shifts between EEG signal and kinetic data. Colour code is an indicator of correlation level.

We have found the highest level of correlation around 2Hz in the low EEG frequency range. Additionally, the 28-36Hz band also shows high correlation level although it is not as pronounced as that in the 2Hz range. The distribution of correlation levels was similar for different kinetic components (hand x, y, z and joint angle at the elbow). Analysis of different velocities (slow and fast) and movement directions shows some diversity in the correlation level although the variance was not significant. The correlation was maximal when EEG signals were compared with parallel registered kinetic data whose results are illustrated at 0ms column in Figure 3.

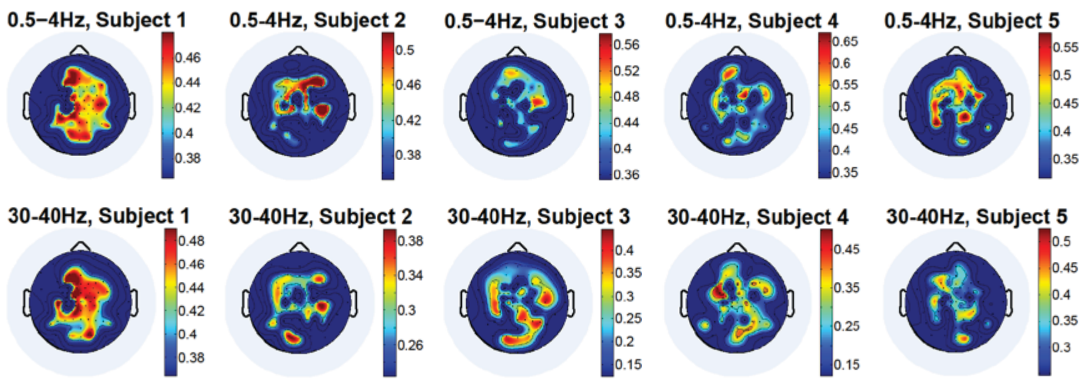

Figure 4A: Correlation between power pattern of EEG bands and Hand(z) trajectory of subject 1-5 (slow tasks)

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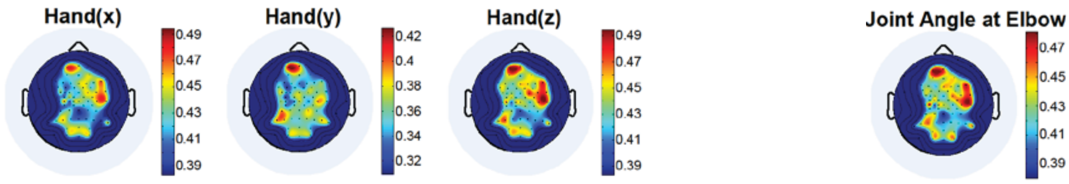

Figure 4B: Comparison of the correlation levels of EEG patterns and kinetic components (0.5-4Hz, slow tasks)

Figure 4A and Figure 4B illustrates distribution of correlation levels in case of parallel recorded EEG signals and kinetic data (time shift = 0) for different cortical areas. Dark blue (background) colour indicates areas where we were unable to collect good quality synchronized EEG and kinetic data in our pilot study for valid statistics. Figure 4A compares results from different subjects and Figure 4B shows the difference when x, y or z vector component of hand trajectory or joint angle at the elbow has been used as kinetic data in correlation. The similarity between Hand (z) and joint angle at the elbow is the highest, compared to x or y. The result indicate the EEG associated with the z direction vector component of the hand movement is more correlated with the joint angle than x or y. The increased frontal and occipital correlation in case of 30-40Hz gamma band [5] highlight importance of these cortical areas in motion trajectory prediction. Our results could not unequivocally support this theory because there are insufficient data gained form some important cortical areas.

5 Conclusion

We have used a correlation analysis to examine the importance of different EEG frequencies, cortical areas and time shift between EEG signals and kinetic data in motion trajectory prediction. We identified strong correlation between EEG and kinetic data in the delta (0.5-4Hz) EEG range which is consistent with repetitive finger movement study from Paek et al. [4]. Furthermore, the correlation in 28-36Hz band was also more pronounced at pre-movement and at movement onset than in the mu, alpha and beta bands. Gamma band activity or 40 Hz EEG is strongly related to planning of a specific movement [6]. We found that the correlation between EEG and kinetic data is maximal when both are registered in parallel i.e., no lag between EEG and Kinetic data.

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