Behaviourally linked cortical oscillations as a means of intention detection.

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Abstract

Using multichannel EEG recording from electrodes placed over the motor cortex with simultaneously recorded EMG signals from wrist muscles we have begun to examine the variability in the beta cortico-motoneuronal coupling seen in normal subjects and in patients recovering from unilateral stroke. Using coherence analysis as the principal method of detecting the presence of beta frequency coupling between the motor cortex and contralateral musculature we have observed that within the normal population a proportion of subjects tested with EEG do not display this feature of motor behaviour. However, in those where it is observed it can be highly repeatable and stable. Similar findings apply to results from the stroke subjects suggesting that the variability seen in beta activity from the motor cortex in normal subjects and patients may limit its usefulness as generic control signal for neuroprostheses. However, in subjects where it is observed it can be shown to be reliably modulated with motor behaviour and offers a novel approach for intention detection.

1. Introduction

There is growing interest in the development of robust methods of intention detection for use in the activation and regulation of prosthetic devices and communication aids for the severely motor disabled. Although, amplitude modulation of electromyograms (EMG) can be used as an actuating signal to control the function of artificial limbs and neuroprosthetic devices its effectiveness as an intention detection system is limited. Part of this limitation relates to the need to attend to the activation of muscle groups not normally associated with the motor function replicated by the prosthesis and the effects of muscle fatigue on EMG signals. Associated with this is a lengthy motor learning/training period that may not be successfully completed by all subjects. Accordingly, over time many amputees provided with myoelectric prostheses will abandon their use. Similarly, voluntarily generated changes in features of the electroencephalogram (EEG) can be used to drive devices (such as communication aids [1,2]) but these systems also suffer from a poor initial relationship to the required behaviour and are hindered by lengthy training periods, are prone to error, and are slow and tiring to use. These features make current EEG systems unattractive for use in the regulation of prosthetic limbs and most existing applications of neuroprosthetic devices.

In identifying signals that can act as intention detection indicators or command signals to prosthetic controllers the chosen signal should have a close relationship with a simple cognitive or motor task that can be accomplished without undue mental effort and importantly should be robust and easy to detect and monitor over time.

Recent research in man [3] and primates [4] has established that a relationship exists between beta activity in localised regions of the motor cortex and the EMG of contralateral muscles recruited to maintained voluntary contractions. Observed in man as a 15-30Hz coherence between cortex and muscle activity this feature of motor behaviour appears to be highly correlated with the performance of this type of motor task and is thought to result from activity transmitted from the cortex to the motoneuronal pool via the corticospinal tract [5]. Its sensitivity to task has been demonstrated by the suppression of beta range coherence during movements [6] and the demonstration that in slow movements an 8-12Hz feature can be seen in the rectified EMG spectrum [7,8,9]. Nevertheless, the detection of modulated spectral features of the EMG that appear to be task dependent and can partly be attributed to rhythmic activity generated within the motor cortex raises the possibility that these signals recovered from EEG could be utilised for intention detection and prosthetic control. The advantage of using signals that modulate with motor behaviour is that the task itself is easy to define and therefore training periods should be reduced. It is the purpose of this study to examine the robustness of EEG signals that reflect this rhythmic activity to determine if they could act as intention detectors or actuators of neuroprosthetics controllers.

Experiments investigating the modulation and EEG and EMG signals and their correlation were performed in a group of normal subjects and a group of patients recovering from unilateral r stroke involving lesions to the corticospinal tract. Preliminary findings from this study are presented here.

2. Methods

All experiments were conducted with ethical approval and the informed consent of the participants.

Each set of experiments required the simultaneous recording of EEG from electrode sites overlying the primary motor cortices and EMG recordings from contralateral wrist flexors and extensors during the

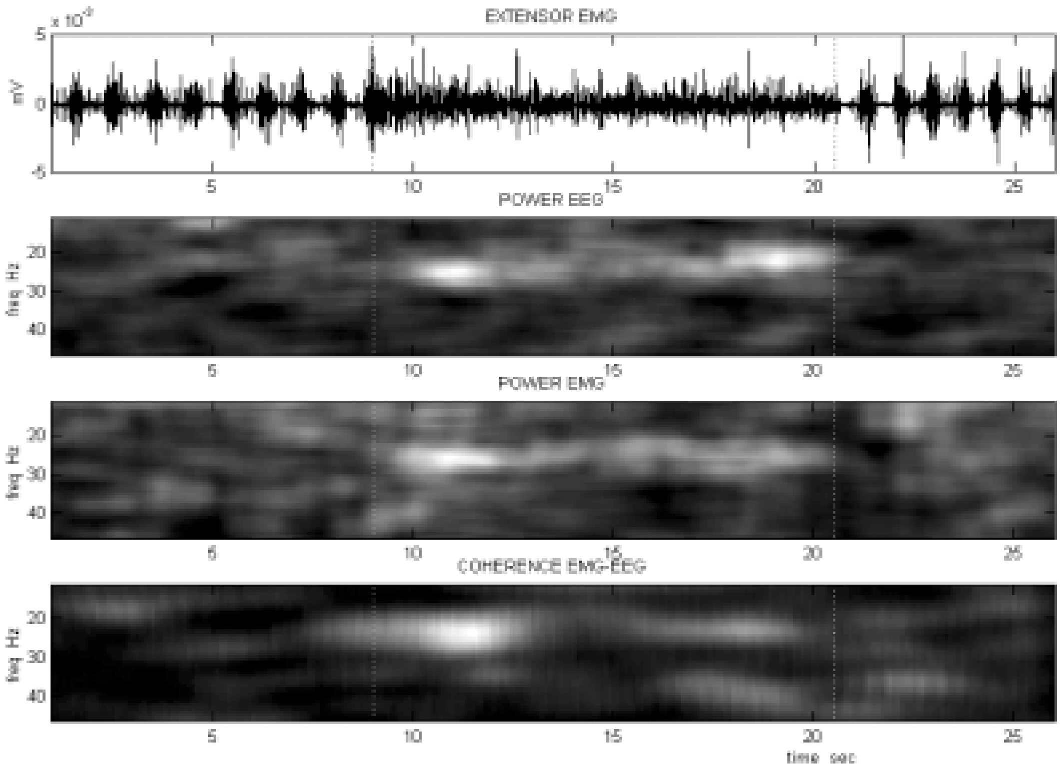

Figure 1. Wrist extensor EMG recorded from a normal subject plotted with its smoothed spectrogram, the smoothed EEG spectrogram recorded from the contralateral motor cortex and an estimate of the time dependent coherence between the rectified EMG and EEG (note for spectrograms and coherence plots the frequency ranges from 10-50Hz)

execution of simple motor tasks. EEG and EMG signals were amplified and filtered (1Hz-500Hz) and EMG (1Hz-500Hz) signals were also rectified. For all experiments the main analysis centred on the estimation of power spectra for each recorded process and the correlation between processes in the frequency domain estimated using coherence [10]. All signal processing was performed using Matlab.

For normal subjects (n=7) the motor tasks studied included the maintenance of fixed wrist postures (.e.g wrist extended or flexed), interspersed with periods of rhythmic alternating flexion extension movements or rest. In addition, a series of tests were performed which examined the effect of performing a precision grip task with two levels of difficulty on the coupling between EEG and wrist extensor EMG. In this task the subjects were required to hold the wrist in an extended position whilst holding a small ring transducer in precision grip between the thumb and first finger. The subjects were instructed to maintain a static wrist position and to maintain grip force at a target level displayed on an oscilloscope screen placed in their visual field. This was performed with the display in high and low gain. With a high gain setting the maintenance of force at the target level is more demanding in comparison to the low gain setting due to the larger deviations observed in the force record. The subject therefore has to may more attention to the precision grip task and focuses less on the wrist extension task.

For stroke patients (n=6) the motor task studied required the subjects to maintain periods of short periods of wrist extension or flexion. All stroke patients recruited to the study presented with a clinical diagnosis of pure motor lacunar stroke that was confirmed by CT scan to involve a visible infarction to the corona radiata or internal capsule. Patients were studied initially in the acute post stroke phase (within 5 days of admission) and subsequently at various times within an 18 week period. An assessment of motor performance using Brunnstrom's stages of motor recovery was performed on each subject prior to each experimental session.

3. Results

During the performance of maintained postural tasks, 2 of the normal subjects participating in the study failed to demonstrate evidence of coupling between the EEG's recorded from the motor cortex and the rectified EMG's. Of the remaining subjects significant 15-30Hz coherence between EEG and contralateral EMG recordings was reliably observed. An examples of this coherence and the accompanying modulation of EEG and EMG power spectra with during a postural task are shown in Figs 1 and 2. In Fig. 1, the wrist extensor

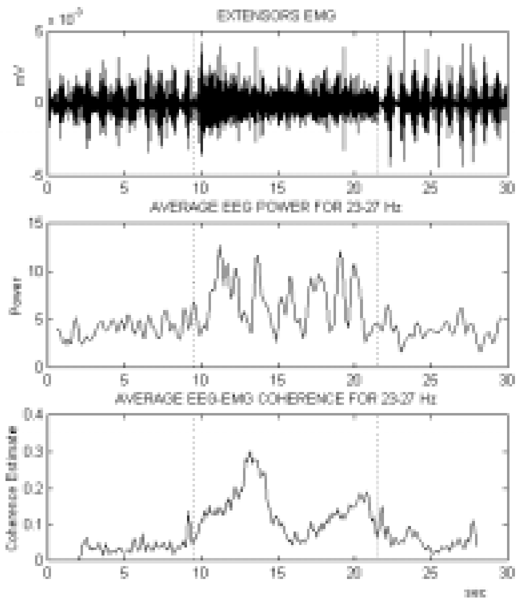

Figure 2. The same EMG record from Fig. 1 plotted together with the estimated change in EEG power and EMG/EEG coherence between 23 and 27 Hz accompanying task performance.

EMG pattern during alternating flexion and extension movements is shown interspersed with a period of maintained contraction of approximately 13s. The slow rhythmic modulation of the EMG during the alternating movements (>1Hz) is clearly seen from the raw EMG. However, the EEG and EMG spectrograms illustrating the change in power in the 10-50Hz range do not show any clear power changes during the periods of alternating activity. However, changes in power can be seen in the EEG and EMG spectrograms in the 20-30Hz range during the maintained contraction. Accompanying these changes is the presence of coherence at 20-30Hz between the EEG and rectified EMG. However, the coherence is not constant throughout the contraction period and this is further illustrated in Fig. 2 where the changes in average power and coherence in the 23-27Hz range are plotted against time along with the EMG record. The results show that coupling between EEG and EMG modulates with task, yet during the task the coupling is not constant. This is a consistent finding in subjects who showing coherence in the 15-30Hz range during maintained contractions.

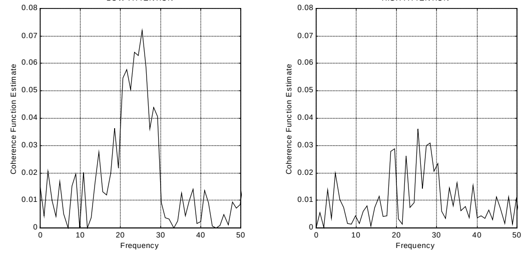

Figure 3. Maintained wrist extension performed with a precision grip task with different attention levels. EEG/EMG coherence is reduced (right plot) when the grip task requires increased attention.

To further explore the variations in coherence during maintained wrist extension subjects were asked to perform an accompanying precision grip task that varied in the degree of task difficulty (see methods). The coherence between EEG and contralateral rectified wrist extensor EMG is shown in Fig. 3 and illustrates that during the condition that requires the subject to concentrate more on regulating grip force the coherence between EEG and wrist EMG is reduced. It would therefore appear that the coherence between cortex and muscle is sensitive to changing levels of attention and suggests that part of the variability in coherence estimates may reflect alterations in subject attention. In Fig. 3, the coherence is reduced when the subject must pay greater attention to the performance of the precision grip task.

An additional aim of this study was to determine if a normal range of coherence between cortex and muscle could be identified in subjects recovering from lacunar stroke where part of the lesion could be identified as involving the corticospinal tract. All stroke subjects tested within the first week post stroke were able to perform the wrist extension task, but the degree of difficulty in doing so varied markedly between subjects and many reported rapid fatigue. Where follow up tests were performed 5 of the 6 subjects should improved motor performance over time with one subject attaining a near normal level of performance. However, in one subject a reduction of performance on the affected side over the testing period was observed. In this subject no significant 15-30Hz coherence could be seen between EEG and EMG recordings.

In the subject gaining a near normal return of motor function, the coherence between EEG and contralateral wrist extensor EMG appeared normal on both the affected and non-affected sides. This is illustrated in Fig. 4 which shows the coherence measured 1 and 17 weeks post stroke. However, this pattern of coherence was not seen in all cases and considerable variation between subjects was observed, with two cases failing to show any 15-30Hz coherence on either the affected or non-affected sides. A more detailed description of the coherences observed in these patients and the relationship to motor recovery will be presented elsewhere.

3. Discussion

This report illustrates that processes contributing to the generation of the 15-30Hz coherence between motor cortex and contralateral EMG show variations reflecting changes in motor task, the level of attention paid to the task and the consequences of lesions to the corticospinal tract. The variability in 15-30Hz coherence can be considered to partly reflect changes in beta cortical activity and the identification of several factors that can influence this feature of cortical activity question its usefulness as a generic control signal for use in intention

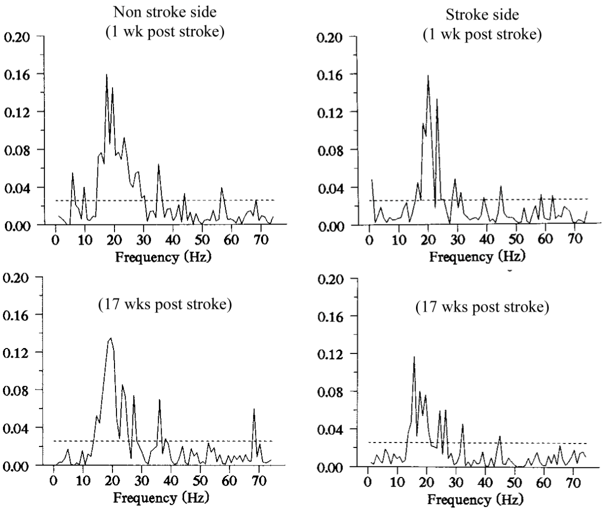

Figure 4. EEG/wrist EMG coherence estimates obtained from a stroke patient showing near normal return of motor function. The left column shows estimates obtained from recordings of EEG from the non-affected hemisphere and its contralateral wrist extensor EMG while the right column shows the results obtained from EEG recordings made from the affected hemisphere and its contralateral wrists extensor EMG.

detection in neuroprosthetics. However, in many subjects this feature of cortical activity can easily be monitored by EEG and is highly repeatable. Accordingly, in these subjects, despite the range of modulatory influences that can influence cortical beta activity a sufficient degree of modulation can be achieved without undue mental effort. This suggests that for selected subjects modulation of beta activity recorded from the motor cortex could serve as a means for intention detection.

5. References

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