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Motor Imagery Mental Tasks in Brain-Computer Interface Applications

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Abstract: Nowadays, motor imagery represents a challenging approach to replace, extend and/or improve different brain skills. It requires intense study and continuous improvements. The current study analyzes and emphasizes motor imagery tasks, showing results similar to those reported by the literature. A non-invasive synchronous Brain-Computer Interface application is investigated based on previous work. Different approaches are tested in order to improve motor imagery results and user's performance in specific mental tasks. Effective training methods are suggested, and the outcomes are assessed based on event related spectral perturbation. The study shows that subject's skills and interests are important when considering motor imagery tasks and speech stimuli provide better results than visual and auditory stimuli.

Keywords: Brain-Computer Interface (BCI), electroencephalography (EEG), electromyography (EMG), motor imagery (MI), event related spectral perturbation (ERSP), stimuli system, brain training, rehabilitation.

1 Introduction

Motor imagery (MI) describes the mental process when a person visualizes a desired action, without really performing it [1]. Its purpose is to improve someone's performance or, moreover, to be part of a rehabilitation program. Regarding motor imagery training, early studies show athletes performance improvements and enhanced functional recovery in patients affected by stroke [2, 3].

A large part of the research is based on healthy subjects experiments, in order to understand brain neural mechanisms or just to train users to communicate with a computer, facilitating their adaptation to motor imagery tasks.

In a previous work, we proposed effective stimuli based on real movement experiments [4]. Continuing this work, we implement similar experiments, including motor imagery tasks, while considering auditory and visual stimuli.

The real movement experiments prepare the subject for more complex motor imagery experiment. The same analysis method was applied, i.e. event related spectral perturbations (ERSPs), in order to determine the mu band events correlated with the imagined movement.

In order to improve user-computer communication and to reduce user-machine adaptation, effective tasks are proposed for left/right hand movement, according to subject individual preferences.

To check that only the motor imagery task is performed, and no real movement is executed, the electromyography (EMG) was synchronously recorded, to observe the muscle activity.

The second section of this article describes the experiment design for the BCI stimuli system, the mental tasks developed for the motor imagery analysis, the acquisition setup and the details on the equipment used to record the data and the proposed processing methods.

The next two sections describe the proposed processing methods, the corresponding brain activity analysis, based on the investigated experiments and the signal processing results.

The last section, Conclusions, advances also perspective developments of the current work, focusing on main signal processing ideas and presents possible improvements for the proposed mental tasks.

2 Experimental Setup and Data Description

The experiments consist in imaging some left or right hand movements, whenever visual or auditory stimuli appear.

2.1 Participants

In order to have a proper comparison to real movement experiments, same healthy right-handed subject, without previous experience in mental practice, was included in the motor imagery experiments. The experiments were performed in a laboratory environment, with 35 dB background perturbations.

2.2 Experimental paradigm

Keeping the same experiment design as in [4], the user was instructed to perform the imaged movements within the trial periods. An experiment consists in 20 trials per event (left or right imagery movement). The subject was instructed to stay relaxed, with the palms over the keyboard surface and not to perform any hand or finger movement.

Stimuli system. Considering previous work results and human senses limitations [4], we use the black and white visual stimuli and an additional auditory stimulus. The experiment performed with visual stimuli uses white cue or a sound for the preparation period, and white arrows on black screen for actual/imaged movements. The cue sound represents a beep of 1200Hz fundamental frequency and 20000 Hz maximum frequency, sampled at 44100 Hz frequency with PCM and provided with 80 dB amplitude. For the auditory stimuli experiment, a speech stimulus was proposed, representing the “left” or “right” commands, depending on the respective trial and participant gender. Normally, speech frequency band ranges between 300 and 3000 Hz [5]. Taken into consideration that frequency band of males is 80-180 Hz and that 150-300 Hz is the frequency range for the female voice, a medium frequency was selected for each situation [6]: for the male subject, a female voice sound of 250 Hz frequency was proposed, whereas and a male voice sound of 100 Hz could have been used in the case of female subjects. For a better focusing, the amplitude of the voice sound is chosen to be 70 dB, slightly louder than normal conversation amplitude [7].

Mental tasks. Ten experiments are proposed based on stimuli and mental tasks mixtures. In order to have a stronger activation in the cortex [8], we request that the tasks will be performed using only kinesthetic motions. This means that the user must mentally perform all the muscle contractions required by the respective movement, which implies a more complex process than just visual imagine the movement. In addition, in order to improve the imagery movements, the subject is asked to perform different mental tasks for each experiment, according to his preferences (Table 1.). The subject’s first hobby is gaming, therefore, a specific task was requested to perform gun trigger pulling, left or right accordingly, besides button press (index finger flexion) and hand lifting imagery motions. In imaginary hand lifting scenario, the user was asked to imagine left or right hand lifting as if he wants to reach the presented visual stimuli. For the auditory experiments, the subject performed the actions with eyes closed, concentrating on the imagined movements.

Table 1. Classification of Experiments for Left/Right Imagery Movements

Experiment types				
Stimuli type	Stimulus presented	Attention type	Mental task	No. of experiments
Visual	white and black stimuli	white cue	button pressing	4
Visual	white and black stimuli	1200 Hz sound	button pressing	2
Visual	white and black stimuli	1200 Hz sound	hand lifting	1
Auditory	speech stimuli	1200 Hz sound	Button pressing, eyes closed	2
Auditory	speech stimuli	1200 Hz sound	trigger pulling, eyes closed	1

2.3 Data acquisition

For brain signal acquisition, the 10-20 unipolar EEG international system montage was used, more precisely, the electrodes C3 and C4, to detect left and right hand imagined movements [9].

To confirm the absence of real movement, the surface electromyogram was also recorded, which detects the muscles contraction corresponding to left or right index finger movement. To oversee all fingers activity, it was decided to record the activity of extensor digitorum communis muscle [10, 11].

In addition to the hardware equipment necessary for EEG data acquisition, two EMG100C modules were added for muscles activity investigation [12]. EMG acquisition was performed in bipolar mode using two EL503 disposable electrodes for each forearm, placed 3 cm away from each other, on the region of interest, parallel with the representative muscle fibers.

The EEG was hardware filtered using a notch filter, a 10 Hz high pass filter and a 500 Hz low pass filter for band signal preserving. The amplifier gain was 5000.

The acquisition was performed using the Acqknowledge 4.0 software [13], and the stimuli were provided by the HW/SW Kit SuperLab 4.0 [14].

3 Signal processing methods

The off-line signal analysis was made using the MATLAB software, version 7.10.0 (R2010a). Moreover, for filtering and frequency analysis, were used different functions and tools within the Signal Processing Toolbox, including tools like: Signal Processing Tool - SPTool (with: signal browser, filter visualization tool - FVTool, Spectrum viewer) and also the Filter Design and Analysis Tool – FDATool, within Filter Design Toolbox.

3.1 EEG processing

For a better EEG noise removal, two filtering techniques were used and the best was selected thereafter, considering the Peak Signal-to-Noise Ratio (PSNR).

The first method involves two filters: a 20th order comb filter and a 50th order band stop FIR equiripple filter.

The second method employs the Interval-dependent Wavelet denoising, using level 5, Daubechies mother wavelet db5, and considering 3 intervals [15].

After extracting the EEG data epochs corresponding to each trial type (left or right) and after baseline removal, the event-related spectral perturbation method is computed to reflect sensorimotor synchronization or desynchronization [16].

ERSP method measures the dynamic changes in amplitude of the band frequency spectrum by a function of time related to stimuli event [17].

In order to reduce the signal perturbation, it normalizes the trial segment over the relaxation segment, corresponding to the background EEG activity.

The normalized response is averaged and its logarithmic spectral amplitude is represented in time-frequency plane. This spectrogram technique allows multiple band analysis. ERSP method involves Fourier analysis (implemented with a Hamming window of 128 samples and 100 overlays) and is expected to reveal spectral perturbations on mu frequency band (8-10 Hz) [18].

3.2 EMG processing

The first step in EMG pre-processing, noise cancelling, demands signal filtering techniques to preserve the signal in the frequency band of interest, 50-500 Hz.

This process requires the following steps: i) subtract the 0.06 V DC offset of the recorded EMG signal in order to remove network interference; ii) electrical noise removal with high pass filter of 10 Hz cutoff frequency; iii) add a 500 Hz low pass filter to remove high frequency harmonics; iv) power line interference cancelling with a 50 Hz Notch filter of third order; iv) random noise reduction with moving average FIR filter; v) signal correction with absolute value; vi) root mean square determination to measure overall muscular effort, i.e. to extract the muscle contractions.

4 Results and Discussions

Starting with the filtering analysis by considering the PSNR, a better signal quality ratio over noise was detected in case of wavelet filtering technique. Improvements are clearly visible when comparing with the FIR methods (Table 2).

Table 2. PSNR Estimation Of Filtering Methods

Signal	PSNR	
	FIR filtering	Wavelet filtering
C4 electrode	10.7859	51.1709
C3 electrode	6.0897	55.6603

Then the sensorimotor activity of left and right hemisphere is revealed by the spectrogram, based on the ERSP method, shown in the following figutes. In Fig. 1-4. the ERSP and ITC time-frequency plots are presented for imaginary button press experiment with visual stimuli and visual attention cue.

The activity corresponding to the motor imagery task involving the right index movement is acquired within the contralateral hemisphere by the electrode C3. As it can be seen in Fig. 1, showing the ERSP, synchronization appears within the mu frequency band (8-10 Hz) and high frequency beta band (16-25 Hz), while for C4 (its activity is analyzed in Fig. 2) non-relevant variations appear. Regarding motor imagery, Event related (de)synchronization (ERD/ERS) activity in mu and beta band is often reported by scientific papers [19].

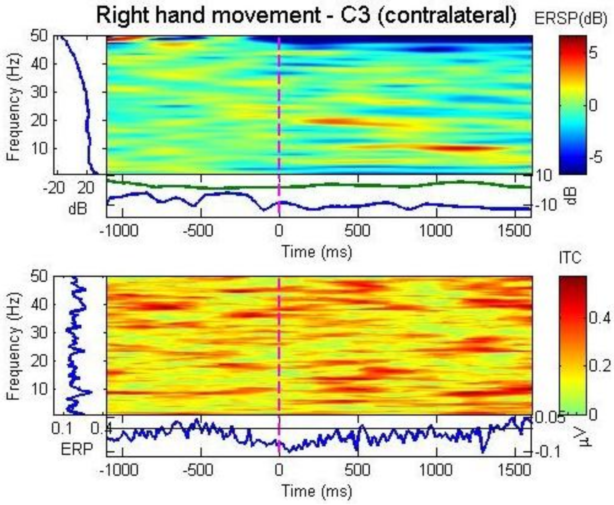

Fig. 1. ERSP and ITC of C3 in right hand motor imagery tasks, when considering the visual stimuli experiment with button pressing mental task. The right color bar shows the relation between colors and power spectral density, in dB or μV.

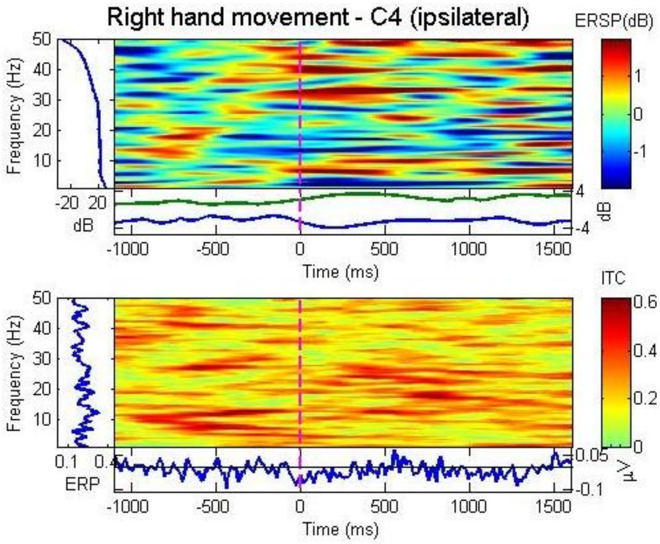

Fig. 2. ERSP and ITC of C4 in right hand motor imagery tasks when visual stimuli are considered with button pressing mental task

In Fig. 3 and Fig. 4, it can be observed that the ERSP and ITC of the left index finger imaginary movement show some perturbations after stimuli presentation in the mu frequency band and a weak synchronization in high beta frequency band. Being right handed, the subject performed not so well the imagery of left hand movement.

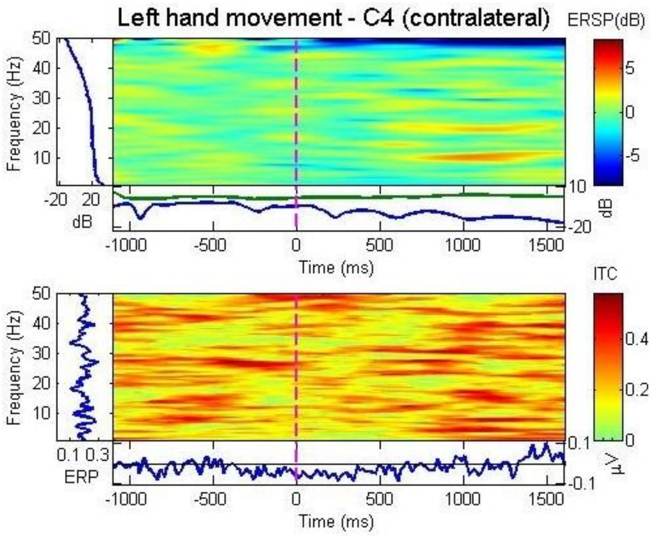

Fig. 3. Spectrogram with ERSP and ITC of C4 activity in left imagery movement for visual stimulus experiment, with button pressing mental task

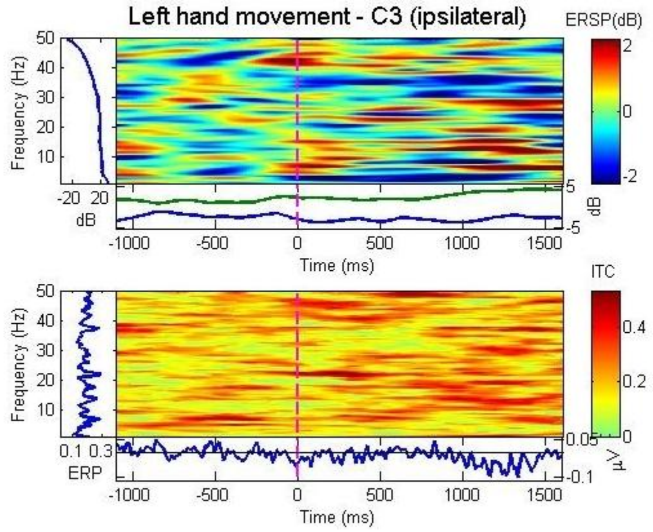

Fig. 4. Spectrogram with ERSP and ITC of C3 activity in left imagery movement for visual stimulus experiment, with button pressing mental task

The most evidenced perturbations were detected in hand lifting and trigger pulling mental tasks. In the following figures can be easily depicted a clear and stronger activation in mu band.

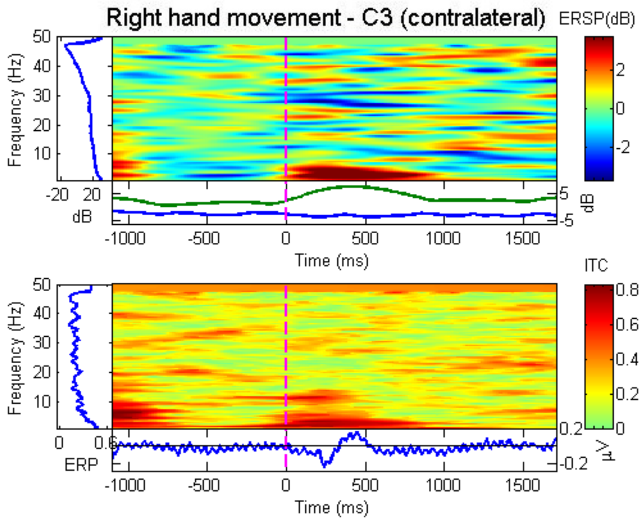

Fig. 5. Spectrogram with ERSP and ITC of C3 activity in right imagery movement for visual stimulus experiment, when performing hand lifting mental task.

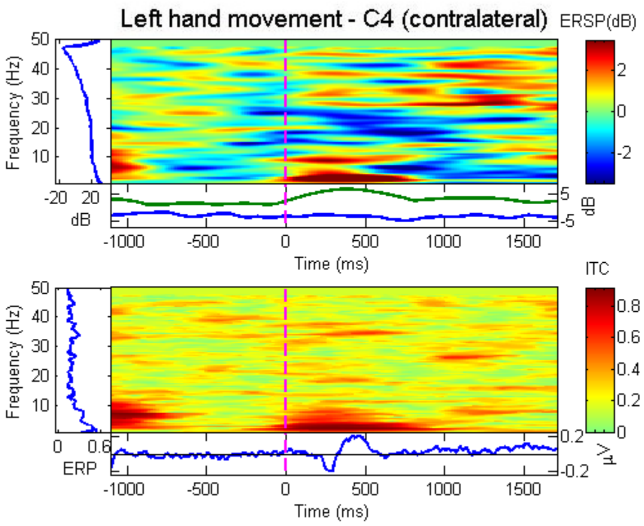

Fig. 6. Spectrogram with ERSP and ITC of C4 activity in left imagery movement for visual stimulus experiment, when performing hand lifting mental task.

As revealed by the participant feedback, the easiest tasks were involved in the gun trigger pulling experiment. Thanks to his hobby, it was more common and interesting for the user to imagine this type of movement, more than imaginary hand lifting and button press. Regarding stimulus type, subject stated increased attention for auditory speech stimulus, but a slow delay in reaction.

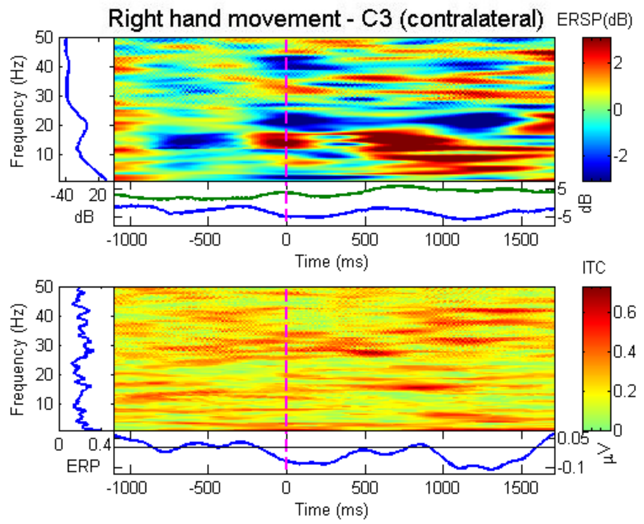

Fig. 7. Spectrogram with ERSP and ITC of C3 activity in right imagery movement for auditory stimulus experiment with trigger pulling mental task.

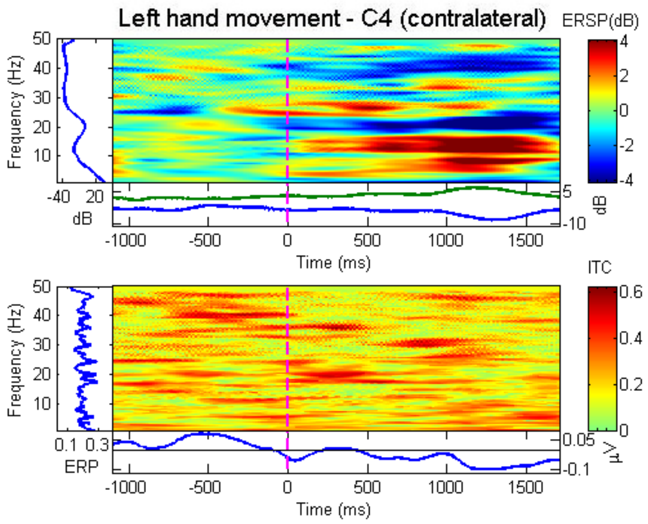

Fig. 8. Spectrogram with ERSP and ITC of C4 activity in left imagery movement for auditory stimulus experiment with trigger pulling mental task.

The next table (Table 3) describes the (de)synchronizations depicted in the spectrogram analysis of motor imagery mental activity within mu and beta bands.

Table 3. Perturbation Patterns for Left/Right Imagery Movements Experiments

Stimuli type	Attention type	Mental task	Mu band (8-10 Hz)	Beta band (14-30 Hz)
Visual	cue	button pressing	ERS	ERS
Visual	sound	button pressing	ERS	ERS
Visual	sound	hand lifting	ERS	ERD
Auditory	sound	Button pressing, eyes closed	ERS	ERD
Auditory	sound	trigger pulling, eyes closed	ERS	ERD

Referring to the real movement execution with visual stimuli [4], it was observed that that same pattern is respected: synchronization in mu band (8 –12 Hz) and desynchronization in higher beta band (14 –30 Hz).

5 Conclusions

The current study proposes novel mental tasks which allow increasing the accuracy of the movements, avoiding user over-loading, and holding meanwhile his interest.

There was an improvement in signal quality when using noise removal method based on wavelet filtering as compared to the classical FIR methods.

Clear-cut results were noticed, i.e. the synchronized neural activity in the mu frequency band (8-10 Hz), which is usually reported in the literature, for example in [20].

The proposed experiments show that it is better to consider the user preferences and his experience, when developing a BCI system.

As revealed by the study, it is more attractive and easily to interact with a machine when the tasks of the developed interface are based on personal hobbies, especially in non-experienced subjects.

As regarding the learning phase, the real movement experiments proved to be efficient enough to allow the subject to communicate with the computer through motor imagery tasks.

The subject also noticed increased imaginary concentration strength in case of auditory stimuli, when the cue was provided via speech signals.

It is interesting to analyze the efficiency of the motor imagery tasks by measuring the strength of the induced brain potentials.

Motor imagery execution performance among mental tasks involves component extraction methods which will be further developed.

Furthermore, it is necessary to evaluate the motor imagery performance while considering also the real movements, using statistical methods.

In addition, more relevant studies will be developed to sustain the proposed mental tasks and the method described in an elaborate experiment with more subjects.

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