Influence of Passive Thumb Movements on μ Wave

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Received 10 November 2002; Accepted 21 February 2003

Abstract

μ wave is the spontaneous EEG activity around 10Hz originating from Rolandic area and is suppressed by voluntary movements. The current study was designed to test whether μ wave was also suppressed by passive movements. The passive movements of right thumb (driven by a custom-made mechanism) of two different frequencies, namely, 5 and 10 Hz, were used as the sensory inputs. Sixteen channels of EEG signals in bilateral central area were recorded with a digital EEG machine with a sampling rate of 256 Hz. Two time-frequency signal processing methods, short time Fourier Transform and wavelet decomposition were employed to analyze the data. Three normal subjects were recruited. The results of both short time Fourier Transform and wavelet decomposition analyses indicated that μ wave on the contralateral somatosensory area was suppressed during passive movements.

***Keywords*:** μ wave, Passive movement, Brain computer interface

Introduction

Electroencephalography (EEG) is a commonly used method for monitoring brain activity. Even though many advanced and sophisticated image studies and scanning techniques have been developed, EEG has several advantages, i.e., low cost, non-invasive, no hazard of radiation and high temporal resolution, that make it still irreplaceable in many medical applications.

μ wave is the approximately 10 Hz rhythmic waveform in the rolandic area. It was well known that voluntary movements of the thumb could suppress μ wave. The suppressive effect was more prominent on the contralateral side and different types of movements produced similar phenomena [1]. Pure imagination of movement without actual action also had similar effect [2]. The suppression was detectable without signal processing in only 10% of subjects [3] and was more prominent in the young population. With improved signal processing techniques, the detection rate after signal processing was close to 100% [4]. The μ wave suppression began approximately 1.5 seconds before the start of actual movement and persisted until the end of the movement [5]. Similar effects on the β wave (~20 Hz) in the same area was also reported, though, when compared with the μ wave, the maximal suppression site located more anteromedially and the rebounding phenomenon started earlier and was more prominent [6].

Previous studies all used active self-paced extension strokes of the thumb as the inputs, because μ wave was generally believed as the resting potential of the primary motor cortex. Kuhlman showed that the center of μ wave suppression was closer to the post-central gyrus, the primary somatosensory area [7]. Results from studies using magnetoencephalography also supported this conclusion [8]. The authors speculated that β wave was the resting waveform of the primary motor cortex and μ wave was the counterpart in the primary somatosensory cortex. There were evidences that mechanoreceptive afferents could produce driving in the somatosensory cortex [9, 10]. Kelly et al. used weak electrical stimulation (~30 Hz) via microneurographic techniques to the fingertip and found frequency-following responses in EEG recording. There were also evidences that light tactile stimuli could suppress μ wave. Yet, there was no direct evidence that passive movements could suppress μ wave.

The main goal of this study was to investigate the effect of passive thumb movements on μ wave magnitude. The hypothesis was that passive thumb movements would provoke sensory inflow to the contralateral primary somatosensory cortex (post-central area) and suppress the μ wave. The results of this study may contribute to the source identification of μ wave and, in the practical side, may help to choose and design the control sources for brain-computer interfaces.

Methods

Selection of subjects

The three subjects recruited in the current study were healthy male college students aging between 18 and 28 year-old. Before the experiment, brief history taking and simple neurological examination was performed by a qualified

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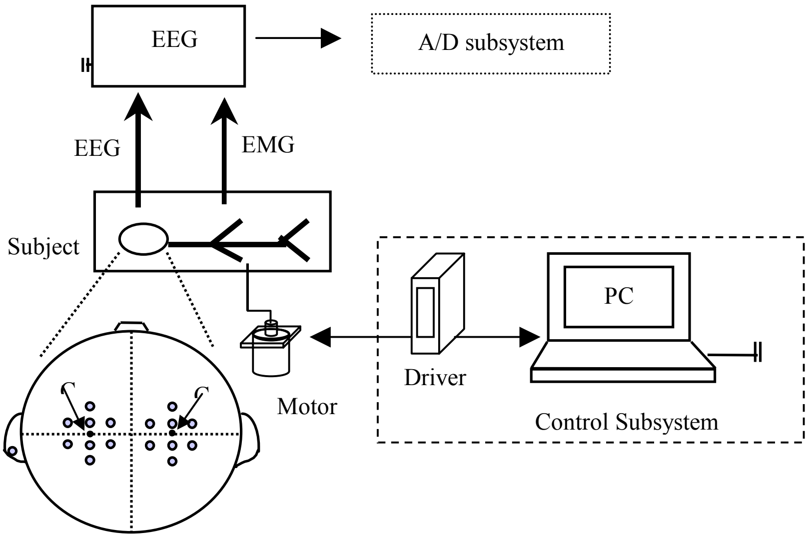
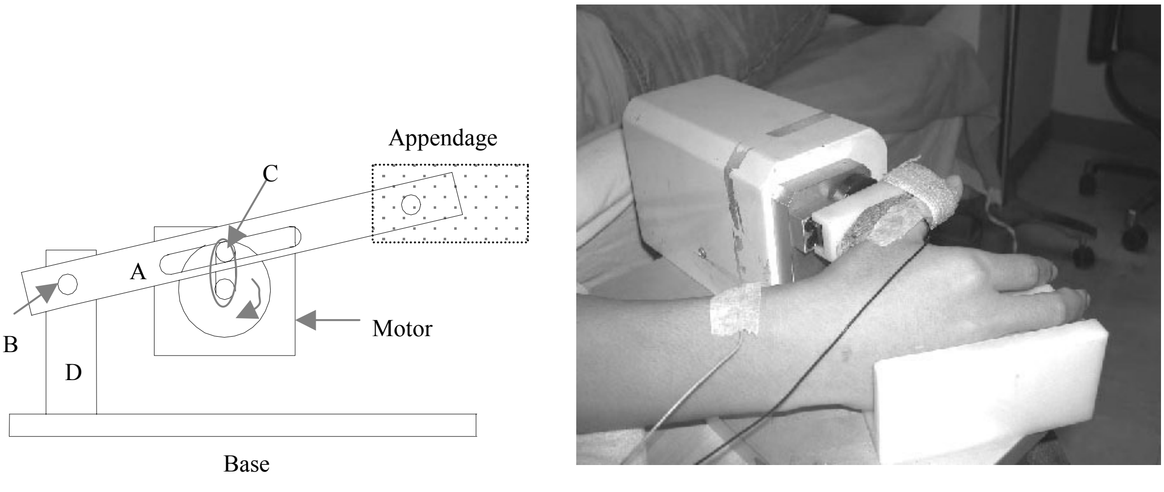


Figure 1. Schematic drawing of the whole experimental setup.



(a) (b)

Figure 2. (a) Schematic drawing of the passive thumb traction mechanism and (b) a picture of the mechanism with the hand of a subject.

neurologist in order to rule out the existence of physical and neurological deficits. The whole experimental procedure was explained in details to the subject and a printed consent form was signed.

Experimental setup (Figure 1)

The experimental setup consisted of both the input (EEG and EMG (electromyography) signals) and output (thumb traction) parts. Sixteen standard EEG cup electrodes were fixed on the scalp and one reference electrode on the left ear. The distance between adjacent electrodes was 35 mm. The arrangement was designed to facilitate Laplacian operation [11] and the locations of the electrodes were referenced to the extended international 10-20 electrode system [12]. One pair of electrodes was fixed on the radial side of right distal forearm over the extensor hallucis longus muscle. Since the subject's thumb was passively moved by the traction mechanism, the purpose of the EMG electrodes was to obtain the motion artifact, instead of voluntary EMG. EEG signals from the scalp electrodes and EMG signal of the thumb extensors were amplified and recorded with a commercial digital EEG machine (Profile, Oxford Instruments Cooperation, www.oxdord-instruments.com). All the data were sampled at 256 Hz/channel with a hardware bandpass filter between 1 and 50 Hz.

The custom-made thumb traction system consisted of the mechanical and the control parts. The basic design of the mechanical part consisted of a four-bar mechanism (Figure 2). The vertical bar D was fixed to the base plate. One end of the grooved bar A was connected to the bar D through a pure rotary joint B and the other end to the thumb fixing appendage. The pin C transmitted rotation torque generated by the motor to the bar A through a groove in the middle of the bar A. The distance between the pin C and the rotation center of the motor could be adjusted so that the magnitudes of the bar A movements and, thus, the thumb movements could be changed .

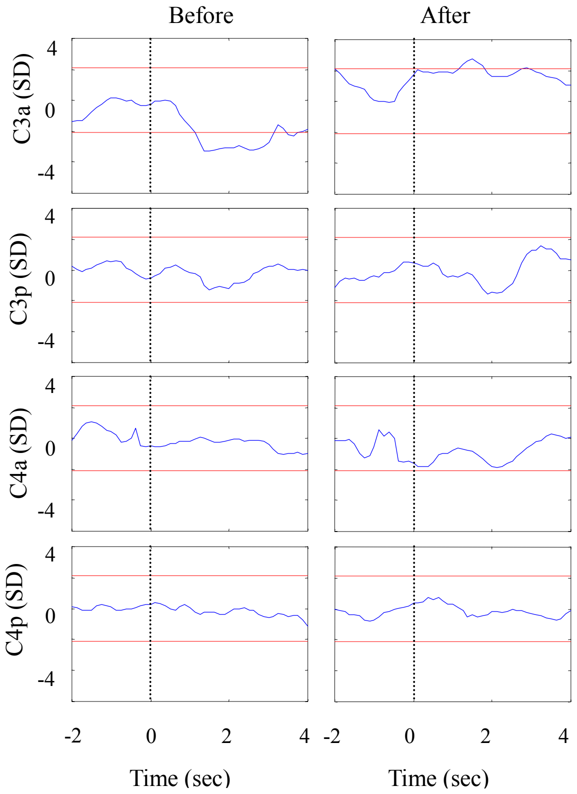


Figure 3. The ERD results of control study on subject 3 analyzed with WT method. The results are normalized with SD (standard deviation of ERD in the baseline segment). The two horizontal lines mark the ±2 SD interval. The left and right columns show the results before and after local nerve block, respectively. C3a and C3p are the points 17.5 mm anterior and posterior to the C3 point, respectively. Designation of C4a and C4p was similar. Zero in the time axis corresponds to the starting point of the movement.

The frequency of cyclic movements was determined by the turning speed of the motor. A motor control card (ValueMotion PCI-4A, National Instruments Corporation, www.ni.com) and the associated high level programming langue LabView (National Instruments Corporation, www.ni.com) was adopted for the control part. Linear PID control was implemented to control the turning speed of the servo motor.

The whole mechanism was covered with a copper-wire web, forming a Faraday cage, for relieving the electromagnetic noises generated by the motor. The whole EEG acquisition experiment was performed in a copper-walled room with the motor control system placed outside the room.

Experimental procedures

The subject lied on the testing bed in a relaxed state and the scalp electrodes were mounted. Another pair of electrodes was attached to the radial side of right distal forearm to record EMG of the thumb extensors. The right hand was placed on the traction mechanism and the right thumb fastened to the appendage of bar A with an elastic bandage. The subject was instructed to remain relaxed throughout the whole experimental period and not to react to the externally imposed thumb traction.

For the control study (performed only in one subject), all the above-mentioned procedures were identical except one additional procedure, the local nerve block, was performed immediately before the experiment. Xylocaine (Lidocaine HCl, 1%) was injected with a syringe both into the carpal tunnel and the anatomical snuffbox of the right wrist in order to block the terminal branches of median and radial nerves, which transmitted sensory signals of the right thumb. The effectiveness of nerve block was assessed by pinprick test of the thumb and index finger.

The magnitude of passive thumb movements was 5 degrees, the frequencies were 5 and 10 Hz and the duration was 5 seconds. Each type of movement was repeated 120 times.

Data analysis

The EMG signal of the thumb extensors was used as a guide to extract the segments of signals affected by the movements. The starting point of passive movement was defined as the point where a sudden increase of slope above a certain threshold in the filtered EMG envelop was detected. A segment of signal, including 2 seconds before the movement and 4 seconds of movement, was sectioned and stored. This procedure was applied to all the channels of EEG signals.

The sectioned data was then processed with Laplacian derivative operation:

$$d^2E/dx^2 + d^2E/dy^2 \tag{1}$$

a spatial filter, to remove the influence of α wave originated from the remote occipital area and to improve the signal quality, where E was EEG (potential field) and, x and y were the arbitrarily chosen orthogonal coordinates of an infinitesimal plane on the scalp adjacent to the point where E was recorded. The operation could be approximated by the equation, E_c-E_s, where E_c is the potential (EEG) of the center point and E_s is the averaged potential of the surrounding points. By this way, four channels of filtered signals were obtained.

We applied both short time Fourier transformation (STFT) and wavelet decomposition (WT) methods to the filtered data and compared the results.

STFT method

STFT was performed on the filtered EEG signals, with a Kaiser window of 1 second in length and 0.125 seconds in moving speed.

Event related depression (ERD) was calculated as ERD = (P - P_r)/P_r, where P was the powers of EEG in the designated frequency band as a function of time and P_r is the mean power of EEG in the first second of the data segment in the same frequency band as P [13]. In this study, the frequency band was chosen as 12-14 Hz. Corresponding segments were then summed up to improve the signal-to-noise ratio.

WT method

Similarly, wavelet decomposition [14] was performed on the filtered EEG signals, with a window of 1 second in length and 0.125 seconds in moving speed. Symlet8 was adopted as

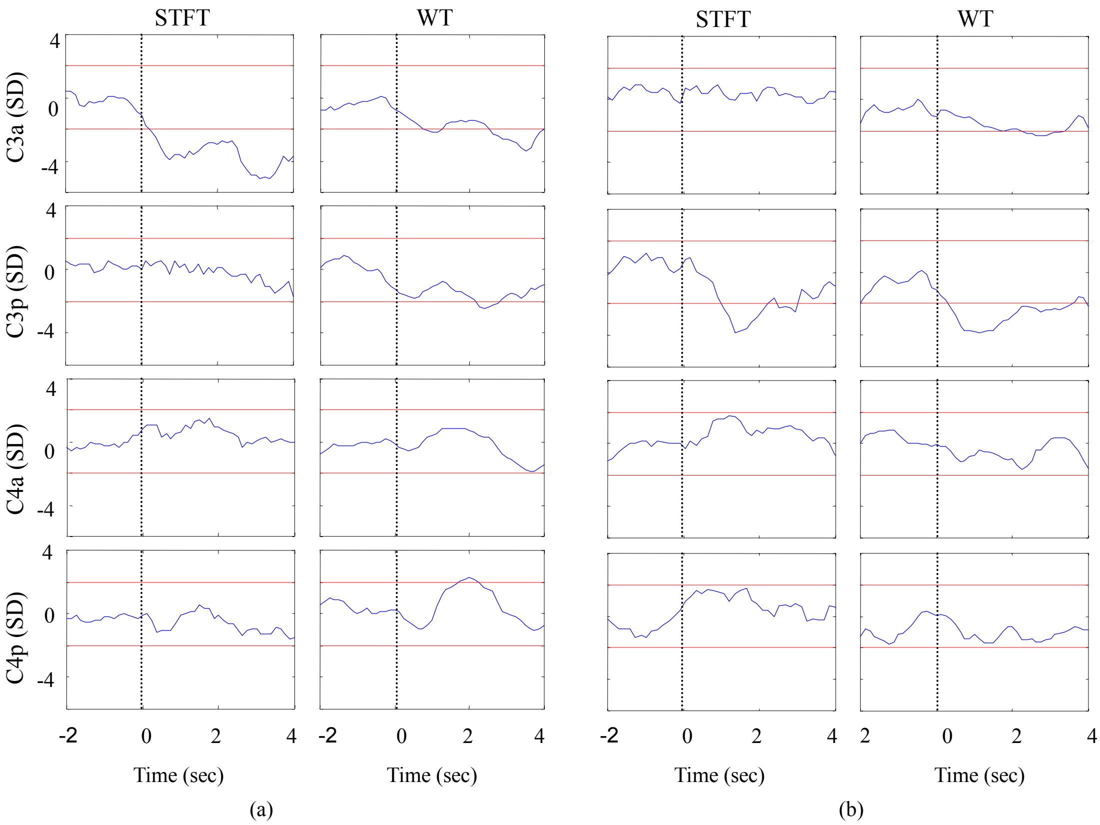


Figure 4. The convention is similar to Figure 3. (a) and (b) are the results of subject 1 and 2, respectively.

the basis function and the EEG signal was decomposed and decimated six times, consecutively. The coefficients in the 12-14 Hz band were used for reconstruction to represent the μ wave. ERD was calculated as described in the previous paragraph.

Statistical analysis

The ERD of the first second of the data segment was designated as the baseline and 95% confidence interval (±2 standard deviations) was calculated. The ERD at other time points were then compared. When the value exceeded the 95% confidence interval, the difference was taken as significant [14].

Results

Control Study

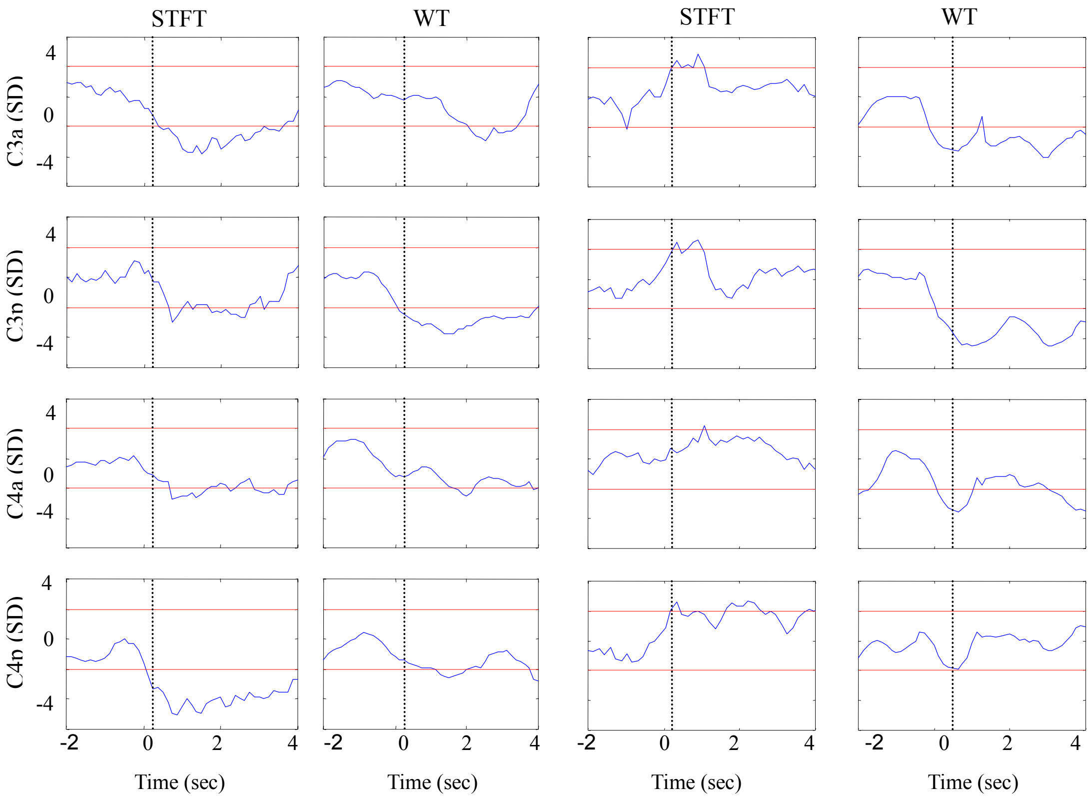
The results of control study analyzed with WT method were shown in Figure 3. Since the effect of local nerve block lasted for less than one hour, only 5 Hz movement experiment was performed. Before the local nerve block, μ wave was suppressed in the contralateral pre-central (C3a) lead. The suppression began about one second after the passive movement was started and lasted for two seconds. The suppression disappeared after the administration of local nerve block. No similar change was observed in other leads. The results indicated that the EEG change was transmitted through the nerve impulses.

5 Hz movements

The results of 5 Hz movements analyzed with both STFT and WT methods were shown in Figure 4. For the subject 1, STFT method indicated suppression of μ wave in the contralateral pre-central lead (C3a), while WT method showed marginal suppression in both the contralateral leads (C3a and C3p). For the subject 2, both STFT and WT methods showed μ wave suppression in the contralateral post-central lead (C3p). The suppression was in the initial 2 seconds. Other leads remained relatively constant.

10 Hz movements

The results of 10 Hz movements analyzed with both STFT and WT methods were shown in Figure 5. For the subject 1, STFT method indicated suppression of μ wave in all the leads with more prominent change in the contralateral pre-central (C3p) and ipsilateral post-central leads (C4a). WT method showed similar changes though the most prominent change was in the contralateral post-central lead (C3p). For the subject 2, STFT method did not show any suppression. WT method showed μ wave suppression in both the contralateral leads and the change was more prominent in the post-central lead (C3p). Other leads remained relatively constant.



(a) (b)

Figure 5. The convention is identical with Figure 4.

Discussions

Noise removal

Because of the enormous noises of different sources in this type of experiments, the control study was performed to make sure that the collected EEG signal was actually the response of sensory inputs transmitted through the neural pathways. The main sources of the noise included the electromagnetic radiation of the motor, the motion artifact due to the passive movements, EMG and the noise of the wall electric power. Many measures were implemented to decrease the effect of noises, i.e., well planning of all the ground wires, building a Faraday cage for the servo motor, moving the motor control unit (including the computer and the driver) to the outside of the room, and well positioning and cushioning of the upper limb to be tested.

Comparison with photic stimulation

As passive movement is the proper stimulus to the somatosensory cortex (post-central gyrus), light is the proper stimulus to the visual cortex (occipital lobe). Photic stimulation is a common way to test the function of α wave in clinical practice. The usual response is a decrease of the α wave magnitude and the appearance of a new wave with the same frequency as the photic stimulation. As mentioned in the above, mechanoreceptive stimuli also showed EEG driving in the somatosensory area [16]. In current study, we did observe suppression of μ wave (the counterpart of α wave). Yet, no new wave was observed (the results were not shown). One possibility might be that the cortical response evoked by the proprioceptive inputs is much smaller than the response evoked by the photic input. It is well known that the cortical response of a single flash often can be seen by naked eye inspection. Yet, the somatosensory evoked potential is visible only after averaging hundreds of trials. The other possibility was that the ranges of stimulus frequencies were different. We used 5 and 10 Hz and Kell et al. used 30 Hz. Further investigation was necessary to clarify this discrepancy.

Comparison of STFT and WT methods

From the results of the current study, WT method was at least as competent as STFT method. WT method produced more localized μ wave suppression in C3p lead, which was compatible with the existing physiological knowledge. At current stage, the number of subjects was too small to confirm this assertion.

Except for one condition (STFT method for analyzing 10 Hz data of subject 1), the suppression of μ wave was more prominent on the contralateral side. The results did not convincingly show whether the suppression was centered on the supposed pre-central or post-central leads. Part of the ambiguity might stem from the uncertainty of correspondence between the scalp lead position and the underneath cortex area.

Conclusion

A custom-made passive thumb traction system was manufactured and used to test the suppression and driving of μ wave by the passive thumb movements. The results showed that μ wave in the contralateral leads was suppressed by the passive movements, indicating μ wave was suppressed by the sensory inputs alone. The results support the notion that μ wave originates from the primary somatosensory cortex and indicate that μ wave alone may be insufficient as the control source of a brain computer interface when the sensory pathways are injured.

Acknowledgements

This work was partly supported by a fund from Taiwan National Science Council (NSC91-2213-E-006-047) and an intramural fund of National Cheng Kung University Hospital (89-042).

References

[1] R. Nashmi, A. J. Mendonca and W. A. MacKay, “EEG rhythm of the sensorimotor region during hand movements,” *Electroencephalogr. Clin. Neurophysiol.*, 91: 456-467, 1994.

[2] D. Klass and R. G. Bickford, “Observations on the rolandic arceau rhythm,” *Electroencephalogr. Clin. Neurophysiol.*, 9: 570, 1957.

[3] H. Gastaut, M. Dongier and G. Courtois, “On the significance of “wicket rhythms” (“rhythmes en arceau”) in psychosomatic medicine,” *Electroencephalogr. Clin. Neurophysiol.*, 6: 687, 1954.

[4] M. Schoppenhorst, F. Brauer, G. Freund and S. Kubicki, “The significance of coherence estimates in determining cerebral alpha and mu activities,” *Electroencephalogr. Clin. Neurophysiol.*, 48: 25-33, 1980.

[5] G. Pfurtscheller and C. Neuper, “Simultaneous EEG 10 Hz desynchronization and 40 Hz synchronization during finger movements,” *NeuroReport*, 3: 1057-1060, 1992.

[6] C. Andrew and G. Pfurtscheller, “On the existence of different alpha band rhythms in the hand area of man,” *Neurosci. Lett.*, 222: 103-106, 1997.

[7] W. Kuhlman, “Functional topography of the human mu rhythm,” *Electroencephalogr. Clin. Neurophysiol.*, 44: 83-93, 1978.

[8] R. Salmelin R and R. Hari, “Spatiotemporal characteristics of sensorimotor neuromagnetic rhythms related to thumb movement,” *Neurosci.*, 60: 537-550, 1994.

[9] E. F. Kelly, M. Trulsson and S. E. Folger, “Periodic microstimulation of single mechanoreceptive afferents produces frequency-following responses in human EEG,” *J. Neurophysiol.*, 77: 137-144, 1997.

[10] G. E. Chatrian, “The mu rhythms,” In: *Handbook of Electroencephalography and Clinical Neurophysiology*, Ed., A. Remond, Amsterdam: Elsevier, 1976 Vol. 6A: 77-89.

[11] D. J. McFarland, L. M. McCane, S. V. David and J. R. Wolpaw, “Spatial filter selection for EEG-based communication,” *Electroencephalogr. Clin. Neurophysiol.*, 103: 386-394, 1997.

[12] H. Jasper, “Report of committee on methods of clinical exam in EEG,” *Electroencephalogr. Clin. Neurophysiol.*, 10: 370-375, 1958.

[13] W. Klimesh, H. Russegger, M. Doppelmayer, T. Pachinger, “A method for the calculation of induced band power: implications for the significance of brain oscillations,” *Electroencephalogr. Clin. Neurophysiuol.*, 108: 123-130, 1998.

[14] J. C. Goswami and A. K. Chan, Fundamentals of Wavelets: Theory, Algorithms and Applications, New York: Wiley Inter-Science, 1999.

[15] G. Pfurtscheller, A. Stancak Jr. and G. Edlinger, “On the existence of different types of central beta rhythms below 30 Hz,” *Electroencephalogr. Clin. Neurophysiuol.*, 102: 316-325, 1997.

[16] E. F. Kelly and S. E. Folger, “EEG evidence of stimulus-directed response dynamics in human somatosensory cortex,” *Brain Res.*, 815: 326-336, 1999.