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Applying stochastic resonance to magnify μ and β wave suppression

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Abstract

The goal was to test whether band-limited sensory noises with adequate amplitudes, by the principle of stochastic resonance, could enhance μ and β wave suppressions. Scalp EEG was recorded while the subject performed thumb movements in the presence of vibratory noises applied to thenar belly or thumb tip. Seven subjects without clear μ or β wave suppression in the absence of the mechanical stimuli were recruited. The results showed that when the stimuli were applied to the thenar belly, both μ and β wave suppressions were enhanced in a bell-shaped trend (the characteristics of stochastic resonance) in four subjects.
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Keywords: Stochastic resonance; μ wave suppression; β wave suppression

1. Introduction

Electrical activities (electroencephalogram, EEG), which reflect the state of brain activations, can be non-invasively recorded on the scalp. μ rhythm is the 8–12 Hz waveform recorded at the Rolandic area of cortex (C3 and C4 of the standard international 10–20 electrode system) while the subject is wakeful and relaxed. Since μ rhythm is suppressed by the voluntary movements and sensory stimuli of contralateral upper limbs [1], it is a potential candidate for the control source in brain–computer interface (BCI) technology [2–5]. The main problem in using μ wave for detecting movement attempts has been the great variability of success rates among subjects. The success rates of many subjects remained low even after extensive signal processing [6–9].

Benzi first noted that, in contrast to the instinctive judgment, a superimposed noise could enhance the detection of desired signals [10,11]. The intensity of noise is very critical. There is an optimal intensity near the detection threshold. When the intensity of noise is either too small or too large, the detection rate is reduced. In other words, the magnitude of response as a function of the noise intensity is bell-shaped. Some investigators took advantage of stochastic resonance to improve the tactile sensation in older adults by electrical noise stimulation [12]. Though stochastic resonance has also been verified in many different biological systems [13], reports of this effect in EEG are only handful. One recent study [14] that investigated stimulating one eye with a subthreshold periodic optical signal and, simultaneously, the other eye with noise light and recording EEG response of the occipital region demonstrated that the phenomenon of stochastic resonance was valid for EEG. The frequency of input periodic signal was 5 Hz and the power spectrum of EEG at 10 Hz was analyzed. In another study [15], authors showed stochastic resonance of EEG in somatosensory area elicited by mechanical tactile stimuli to the middle finger. The EEG content of the same frequency band (2.5 Hz) as the input signal (periodic mechanical stimuli) was analyzed. The effects of noise on the other frequency bands of EEG were not mentioned. If the phenomenon of stochastic resonance is also valid for μ wave suppression during the thumb movements, then it may be possible to design devices accordingly to improve the detection rate of movement attempts. Since the input noise is a sensory stimulation and the output measure is related to motor attempts, the whole system tested involves the sensory pathway, the motor attempt generator and the integration center of motor-sensory information. The whole

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system is very complex. As far as the authors know, there is no existing study report to answer this question.

The main purpose of this study was to investigate the existence of stochastic resonance in μ wave suppression where the noise input was the tactile stimulation. The working hypothesis was that the stochastic resonance also existed in μ wave suppression during thumb movement and that superimposing a band-limited random tactile stimulation with a proper intensity could produce larger μ wave suppression during the movements.

2. Methods

2.1. Experimental setup (Fig. 1a)

The experimental setup consists of two subsystems, namely, the bio-signal acquisition system and the stochastic tactile stimulator system. The bio-signal acquisition part was responsible for recording EEG and EMG (electromyography) and the stochastic tactile stimulator provided mechanical stimulus to the hand.

EEG was recorded by using a commercial digital EEG recorder (Profile, Medelec, Oxford Instrument, http://www.oxford-instruments.com) and all experiments were performed in a shielded room. Eleven channels of signals, including 10 channels of scalp EEG and one channel of surface EMG from the right thumb extensor, were recorded, respectively (Fig. 1b). All EEG electrodes were referenced to the left earlobe (A1). The four electrodes, each 2 cm from C3 and forming a cross (Fig. 1c), were used for spatial filtering at the software level. The four electrodes surrounding C4 were used similarly. EMG of thumb extensor was used to define the onset time of thumb movements. EEG signals were filtered by a 0.5–100 Hz analog bandpass filter, amplified by 10 000× and sampled at a rate of 256 Hz per channel. EMG was also amplified, filtered and sampled at an identical rate by the same EEG machine.

2.2. Mechanical stimulator

The main function of the stochastic tactile stimulator was to produce pointed mechanical stimuli (pointed blunt stabs) on skin with adjustable intensity and frequencies. More specifically, (1) the size of the stimulator had to be small enough so that the device could be fixed on the thumb and would not interfere with the thumb movements and (2) the frequency response had to be linear in the 0–50 Hz range, so that the device could be easily driven to produce band-limited random mechanical stimuli with specified intensities.

Fig. 2 shows the size and structure of our custom-made mechanical stimulator. In order to characterize the dynamics of the stimulator, we used pseudo random binary sequence as the command to drive the stimulator and a proximeter to record its response (Fig. 3a). It was clear that the response is fairly linear when the frequency was below 1000 Hz. An empirical model of the stimulator as a second-order system (Fig. 3b) was identified by least squares method

$$\frac{-0.1601s^2 - 1290s - 5.363 \times 10^6}{s^2 + 538.3s + 1.172 \times 10^7} \quad (1)$$

In repeated tests within 50 Hz, the model simulation results matched with the real responses faithfully.

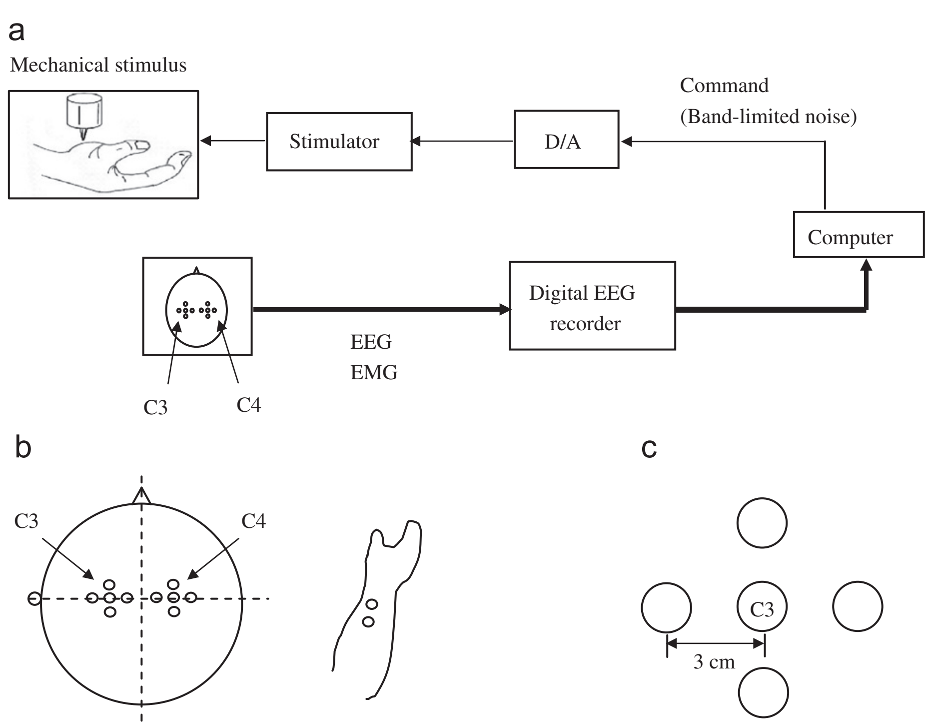

Fig. 1. Schematic drawing of the experimental setup. (a) The whole setup, (b) electrode location and (c) the electrode configuration around C3 electrode.

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