# Hemodynamic responses can modulate the brain oscillations in low frequency

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## Abstract

Previous studies have showed that the steady-state responses were able to be used as an effective index for modulating the neural oscillations in the high frequency ranges (> 1 Hz). However, the neural oscillations in low frequency ranges (<1 Hz) remain unknown. In this study, a series of fNIRS experimental tests were conducted to validate if the low frequency bands (0.1 Hz - 0.8 Hz) steady-state hemoglobin responses (SSHbRs) could be evoked and modulate the neural oscillation during a serial reaction time (SRT) task.

**Keywords**: fNIRS, hemoglobin, brain oscillation, serial reaction time

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# I Introduction

Steady-state responses (SSRs) are evoked by a repetitive stimuli whose frequency components remain stable in amplitude and phase over time [1]. Recent years have witnessed the widely application of SSR in neuroscience filed and brain-computer interface studies [2]. This form of response is based on the synchronous brain response of large numbers of neurons to a temporally modulated stimulus and may reflect the brain activities or neural oscillations [3, 4]. The steady-state evoked potentials (SSEPs) are one of the most studied SSRs and have been shown to be an effective index for modulating the neural oscillations in the high frequency ranges (> 1 Hz). However, the neural oscillations within the low frequency ranges (<1 Hz) remains largely unknown. Compared with the electrophysiological techniques such as EEG, ERP, MEG, fNIRS can measure the cerebral changes in oxy-hemoglobin (HbO) and deoxy-hemoglobin (HbR). In this study, our aim is to use fNIRS [5-8] to investigate whether the steady-state hemoglobin responses (SSHbRs) in the slow frequency bands (0.1 Hz - 0.8 Hz) could be evoked during a serial reaction time (STR) task.

# II Materials and methods

The present study was approved by the Biomedical Ethics Board with Faculty of Health Sciences at the University of Macau (Macao SAR, China). After providing the written informed consents, twelve healthy college students (six males and six females) from University of Macau participated in this study. All the right-handed participants were free from known neuropsychiatric illness.

A finger sequencing reaction time task, in which the index finger to ring finger of participants' non dominant hand (left hand) were trained to perform a specific serial, was used in our steady-state-design study as shown in **Fig 1**. During the task, subjects were instructed to keep their head still and focus their eyes on the cross located at the center of the grey computer screen. The subjects were required to perform the key-press task whenthe blue asterisk presented at the center of the screen. All the subjects were asked to respond as fast and accurately as possible. The order of finger movement sequences was 1, 2 and 3. The tasks were designed as follows: 3-index finger, 2-middle finger and 1-ring finger. The subjects put their index finger, middle finger, and ring finger of left hand on the horizontally placed keyboard in the numeric keypad (**Fig 1A**). The blue asterisk appeared and remained on the screen for 100ms. The simple visual stimuli have been widely used in most SSEP studies. The frequency of the serial reaction time (SRT) task was 0.2 Hz (once every 5 seconds for one stimulus). The fNIRS recording session contained 66 sequence trials lasting about 330 seconds for each subject to perform the task. During each task, the subjects were instructed to remain completely focused without counting or thinking about the stimuli.

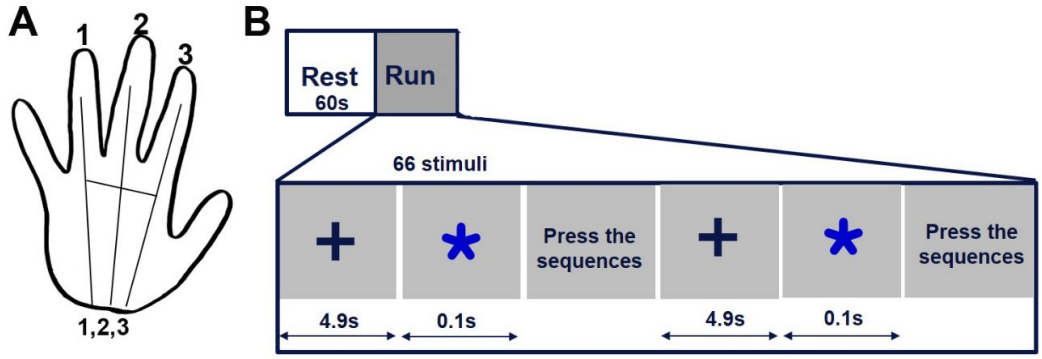


**Fig. 11** Study design. A) The sequences corresponding to the non-dominant hand. B) The fNIRS imaging session design. The task part includes 66 stimuli (0.1s per the blue asterisk and 4.9s per the fixation in one stimulus). Note that the sequences were performed at a self-paced rate and the stimuli were represented at the rate of 0.2 Hz.

Our CW system (CW6, TechEn Inc., MA, USA) consisted of four near-infrared light source emitters containing a 690 nm and 830 nm laser light and eight detectors. The distance between the source and detector was set to 30 mm. The sampling rate was 50 Hz. The middle central (Cz) position of the international 10–20 system was the marker for localizing the motor areas including the M1, PMC, SMA and PFC. The 4 sources and 8 detectors generated 13 source-detector pairs and totally 13 channels in the right hemisphere. The right M1 was covered by channels 1, 2, 3 and 4, PMC was covered by channels 5, 6, 7 and 8, SMA was covered by channels 11, 12 and 13, and PFC was covered by channels 9 and 10. **Fig 2** shows the placement of the arrays.

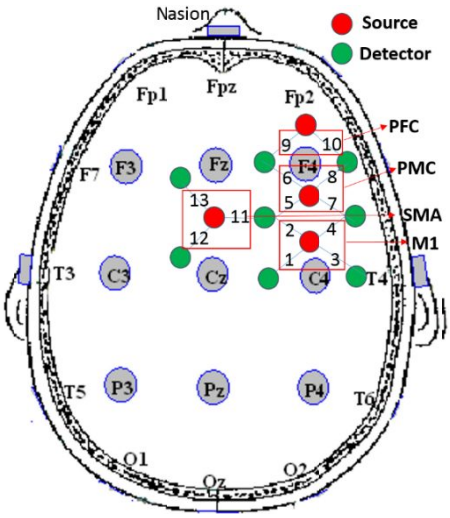


**Fig. 2** Probe arrangements for the subjects. The red and green solid circles indicate the positions of sources and detectors, respectively. The red rectangles represent the ROIs in this study and the numbers stand for the source-detector pairs, or channels.

## III Results and discussion

The preprocessing of NIRS signal was performed using the HOMER2 psoftware. The region-of-interests (ROIs) were defined as the same for each subject as follows: the M1 covering the channels from 1 to 4, the PMC covering the channels from 5 to 8, the SMA covering the channels from 11 to 13, the PFC covering channels from 9 to 11 (as shown in **Fig 2**). In this study, we mainly focused on the HbO signals of each ROI for all participants.

The power analysis provided the power information of frequencies within a signal as a function of frequency. For each subject, each ROI's HbO and HbR time-series were converted to the frequency domain signals using a Fast Fourier Transform (FFT) algorithm. FFT was the most widely used method to define the SSHbR. The data was detrended to remove the baseline shifts. In this study, the low frequency component defined as 0.1 Hz - 0.8 Hz was selected to test the frequency specific power which was induced by SRT task. All spectra of the frequency component showed obvious peaks of the FFT of the signals at about 0.2 Hz, 0.4 Hz, 0.6 Hz and 0.8 Hz frequencies. To evaluate the power changes, the power for each subject for each ROI was obtained in the four frequencies (0.2 Hz, 0.4 Hz, 0.6 Hz and 0.8 Hz). The FFT presented a low frequency fluctuation peak. **Fig 3** showed the average FFT results of all subjects.

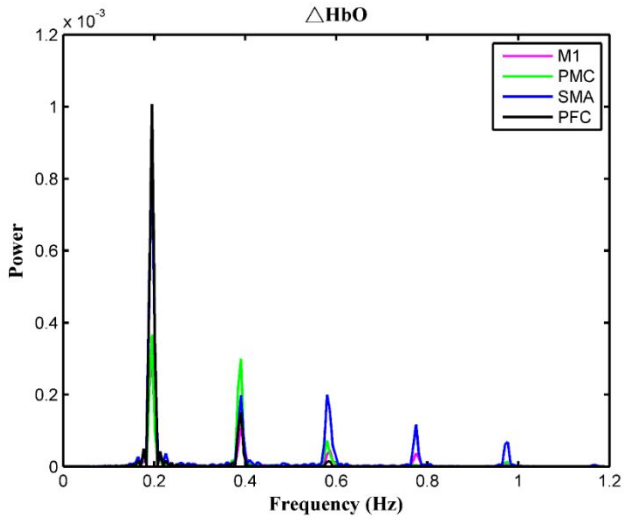


**Fig. 3**. The grand-average of task evoked SSHbRs at the regional brain level. SSHbRs are represented by the mean power at 0.2 Hz, 0.4 Hz, 0.6 Hz and 0.8 Hz. In the 0.2 Hz, SSHbRs were significantly induced.

This study is, as far as we know, an account of the first ever study to investigate the low frequency bands steady-state hemoglobin responses (SSHbRs) using fNIRS. In this study, we have successfully induced the SSHbRs in the low frequency bands. The present study shows that there is a reliable neural response to the stimuli.

## Acknowledgment

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