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Asymmetry Brain Function in Auditory Cortex: A Functional Near-Infrared Spectroscopy Study

Hendrik Santosa & Keum-Shik Hong, *Senior Member, IEEE*

***Abstract*— functional near-infrared spectroscopy (fNIRS) can measure the change of hemodynamic response, it enables to determine the concentration changes of oxy-hemoglobin and deoxy-hemoglobin. The aim in this paper is to investigate the forms of lateralization or asymmetry brain function in auditory cortex using fNIRS. This technique shows good promise for assessment of asymmetry functions in the auditory cortex.**

I. Introduction

In recent years, a new technique for brain-imaging conciliating spatial and temporal resolution, functional near-infrared spectroscopy (fNIRS) [1], has been used. fNIRS is a non-invasive technology for monitoring neuronal activation coupled hemodynamic response using near-infrared light of two wavelengths which 650 nm and 950 nm [2]. By measuring absorption of lights, fNIRS enables determination concentration of the changes of oxy-hemoglobin (HbO) and deoxy-hemoglobin (HbR) in specific of human brain using modified Beer-Lambert Law. This technology has been applied to the study of various applications, such as: neurology (disease) [3], psychiatry (disorder) [4], psychology (emotion) [5], and basic research (brain-computer interface) [6]. fNIRS offers advantages of noninvasive, safe, portable, and inexpensive [2].

The human hemispheres differ in their anatomy and function. Recent studies in magnetic resonance imaging (MRI) studies have been documented anatomical difference between the hemispheres. For functional structures, the cortical mechanisms for audio processing are functionally asymmetrical in the human brain system: According to the earlier findings, the left hemisphere is dominant in the speech processing while the right hemisphere is specialized in the music processing.

Several studies have applied electroencephalogram [7], magnetoencephalography (MEG) [8], positron emission tomography [9], and functional magnetic resonance imaging (fMRI) [10] to study neuronal activation in the auditory cortex. fNIRS is suitable to study in the auditory cortex because it is much quitter than MRI system. These benefits enable subjects to be tested under relax conditions. Compare with fMRI, it is difficult to study in auditory cortex because fMRI measurements are accompanied by acoustic noises resulting from slice selection pulses, cryogen pumping, and magnetic resonance gradient noise. The noise might interfere with stimuli designed to evoke neuronal activation because it sounds loud, noisy and annoying. For example, it shows that the change of HbO in the sensory motor cortex decreased with increasing noise [11]. However, the studies on hemodynamic response using fNIRS in the auditory cortex areas are relatively rare.

Both fMRI and fNIRS signals represent changes of hemodynamic responses in the specific human brain. While fMRI signals reflect changes in blood flow, fNIRS signals can directly measure changes in hemodynamic, HbO and HbR. fMRI signals are physiologically ambiguous, because it depends on changes in cerebral blood flow, cerebral blood volume, and oxidative metabolism. There are many studies of the correlation between fMRI and fNIRS signals [12]. The fMRI signals corresponds to a negative HbR [13] and a positive HbO [14]. In this study, the results focus on the HbO parameters because more robust result compared to HbR.

The aim of this paper is to confirm the predominant role of the right hemisphere in music processing. Three conditions of noise mixing with music (silent, medium, and high) were selected from white noise and presented to healthy participants while evoked auditory cortex activation was measured with fNIRS.

II. Theory

A. fNIRS measurement model

In fNIRS measurements, changes of HbO and HbR are computed using the modified Beer-Lambert Law [1,15]

$$\begin{aligned}\Delta\phi^i(\lambda,t) &= -\ln\frac{U^i(\lambda,t)}{U_0^i(\lambda,t)} \\ &= \left[a_{HbO}(\lambda)\Delta c^i_{HbO}(t) + a_{HbR}(\lambda)\Delta c^i_{HbR}(t)\right] dl^i,\end{aligned} \tag{1}$$

where i is the channel index, λ is the wavelength of the laser sources, $\Delta\phi(\lambda,t)$ is the optical density at time t, $U_0(\lambda,t)$ and $U(\lambda,t)$ are the photon at the source and detector positions, respectively, a_{HbO} and a_{HbR} are the extinction coefficients of HbO and HbR, respectively, Δc_{HbO} and Δc_{HbR} are the concentration changes of HbO and HbR in μM, respectively, d is the differential path length factor, and l is the distance between the source and the detectors.

H. Santosa is with the Department of Cogno-Mechatronics Engineering, Pusan National University, Busan 609-735, Korea (e-mail: santosa@pusan.ac.kr)

K.-S Hong is with the School of Mechanical Engineering and Department of Cogno-Mechatronics Engineering, Pusan National University, Busan 609-735, Korea (phone: +82-51-510-2454; fax: +82-51-514-0685 ; e-mail: kshong@pusan.ac.kr)

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B. Paired t-test

The model underlying the paired *t*-test can be used to test the null hypothesis. This is the simplest model available and the design matrix consists of just constant regressor [16]. The model is

$$Y = X\beta + e, \tag{2}$$

where Y is the column vector of observations, e the column vector of error terms, and β the column vector of parameters; $\beta = [\beta_1,...,\beta_1,...,\beta_L]^T$. The $J \mathbf{x} L$ matrix X, with jl^{th} element x_{jl} is the design matrix. It has one row per observation, and one column per model parameter. The design matrix is to predict the expected signal was produced by fNIRS measurements.

The ordinary least-squares parameter estimate $\hat{\beta}$ is given by

$$\hat{\beta} = \left(X^T X\right)^- X^T Y = X^- Y. \tag{3}$$

The error covariance matrix is then given by $\hat{\sigma}^2 \mathbf{V}$. The covariance of the parameter estimate is

$$\mathbf{Var}\left(\hat{\beta}\right) = \sigma^2 X^- \mathbf{V} X^{-T}. \tag{4}$$

A *t*-statistic can then be formed by dividing a contrast of the estimated parameters $c^T\hat{\beta}$ by its estimated standard deviation:

$$T = \frac{c^T \hat{\beta}}{\sqrt{\hat{\sigma}^2 c^T X^- V X^{-T} c}}. \tag{5}$$

III. Methods

A. Participants

Three male students participated in the experiment (aged 24-28 years, all participants had normal hearing and none of whom had a history of any neurological disorder). The participants were asked to sit in a chair and listen a music presented via earphones (Sennheiser IE7; in-ear ear-bud with over-the-ear mount, binaural) at the same level for all participants. The data were acquired with a continuous-wave NIRS imaging system (DYNOT: DYnamic Near-infrared Optical Tomography; NIRx Medical Technologies, Brooklyn, NY) at a sampling time 1.81 Hz. Fig.1 shows the 16 optodes were placed on the left and right auditory cortex. The inter-optode distance is 2-3 cm. The use of optodes produced a total of 26 channels.

B. Stimulus

In the experiment, the audio stimuli were presented in a random order to maximize stimulus variability. The following experiment presented in three conditions which varying length is 15 seconds (NS = noise silent, NM = noise medium, NH = noise high). The music was repeated three times which is 195 seconds duration for each music. Approximately, the total duration of the experiment was 8 minutes and 45 seconds as shown in Fig. 2.

C. Processing

The neuronal activation coupled hemodynamic response is affected by the changes of low-frequency oscillation in the brain, respirations, and cardiac process. These noises were removed by a low-pass filter (LPF) with frequency cut-off 0.15 Hz for first group of data. To analyze the fNIRS data, NIRS SPM was used with custom software programmed in Matlab ® (Math-works, Natick, MA). The design matrix included boxcar regressors, which convolved with a Gaussian hemodynamic response function (HRF) to predict neuronal activation coupled change of hemodynamic responses.

IV. Result

We evaluated the influence of background noise in three conditions mixing with music signals by measuring hemodynamic responses from every subject. Fig. 3 shows the *t*-value using (5) in the activation maps. It shows oxy-hemoglobin increased in response to music stimulation which is defining the region of interest (darker color) for the different noise levels. However, the response may not change the lateralization after masking the music with background noise. This result confirmed for predominant roles of the right hemisphere in music processing. Table 1 shows a complete list for all subjects of the amplitude mean in the region of interest of the fNIRS signals.

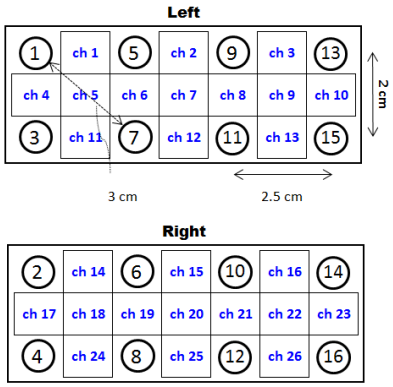

Figure 1. Optodes configuration of the 26-channel fNIRS placed over the scalp in the left and right hemispheres of the auditory cortex.

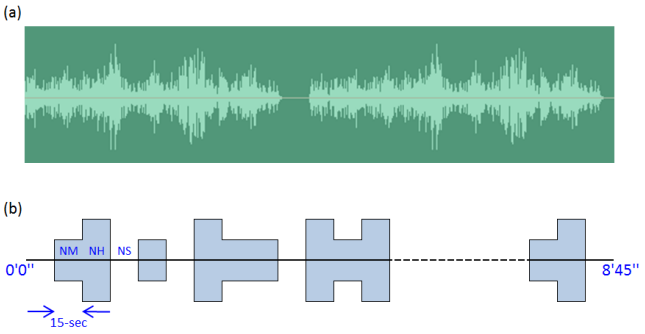

Figure 2. Experimental paradigm: Mixing (a) Für Elise music and (b) Three noise condition in pseudo-randomly presented NS = noise-silent, NM = noise-medium, and NH = noise-high.

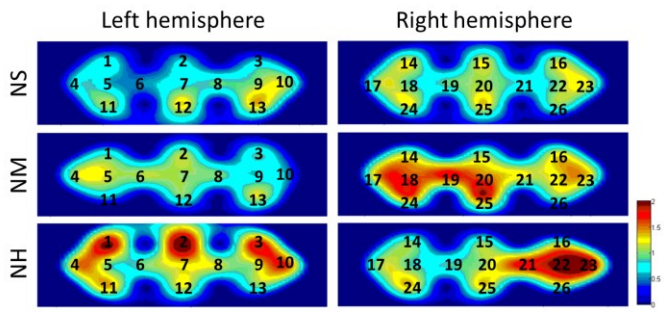

Figure 3. Activation maps for HbO in auditory cortex evoked by mixing music and noise in three categories

Table 1. HbO amplitude from all subjects (in relative unit)

Subject	NS		NM		NH	
	L	R	L	R	L	R
1	63	67	106	111	120	130
2	60	67	75	111	94	126
3	74	80	76	97	96	110

*Scaled 10^4

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