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Prefrontal cortex activation during a dual task in patients with stroke

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ABSTRACT

Dual tasks destabilize task performance as they involve competing demands for cognitive and physical resources. Several studies have reported that dual-task walking activates the prefrontal cortex (PFC), and recent studies have indicated a relationship between PFC and dual-task deterioration in healthy subjects. However, PFC activity during dual-task walking in stroke patients remains unclear. We investigated the association between PFC activity and dual-task interference on physical and cognitive performance in stroke patients. This study included 14 stroke patients and 14 healthy subjects who performed a calculation task while walking at a comfortable pace on the floor. PFC activity was assessed using wearable near-infrared spectroscopy. The calculation task and trunk linear accelerations were evaluated as measures of cognitive and physical performance. The dual-task deterioration on both physical and cognitive performance of stroke patients was significantly higher than in healthy subjects. PFC activation during dual-task walking was significantly lower in stroke patients. Although right PFC activation was negatively correlated with dual-task deterioration on physical performance in stroke patients, left PFC activation was negatively correlated with the dual-task cost on cognitive performance in healthy subjects. Thus, during dual-task walking, PFC activation might prioritize physical demands in stroke patients, but might prioritize cognitive demands in healthy subjects.

1. Introduction

Dual tasks are considered to be destabilizing task performances because they involve competing demands for cognitive and physical resources. This effect is termed as the dual-task cost, wherein cognitive-motor interference can cause deterioration of one or both tasks [1,2]. The dual-task cost can be observed more consistently in older adults, in whom dual-task walking is commonly known to reduce gait speed and cognitive performance. This deterioration of both cognitive and physical performance under dual-task conditions is considered to result from prioritization of gait stability over the cognitive task to compensate for diminished postural control in older adults, a phenomenon termed the “posture-first strategy” [3,4]. Moreover, the effective prioritization of simultaneously performed tasks can be impaired, resulting in an increased fall risk when cognitive flexibility is limited [4,5].

Several studies have reported that dual tasks activate the prefrontal cortex (PFC), which plays an important role in executive functions such as attention and multi-tasking [6]. The PFC activity during dual-task walking in older subjects is lower than in younger individuals [7], which emphasizes the association between lower PFC activity and an increased risk of falls in the elderly. Hence, the change in PFC activity might influence the fall risk in stroke patients. However, the difference in PFC activation during dual tasks between stroke patients and healthy subjects remains unclear [8]. A recent study reported that the influence of PFC activation on dual-task costs differed between young and older subjects [9]. However, to our knowledge, no study has investigated the association between dual-task cost and PFC activation in stroke patients during dual-task walking. An assessment of the correlation between PFC activity and dual-task deterioration could be useful for determining the fall risk in stroke patients.

The study aimed to test the following hypotheses. First, PFC activation in stroke patients with hemiparesis during dual-task walking would be lower than that in healthy subjects because previous studies have reported that PFC activation in subjects with poor physical performance during dual-task walking was lower than that in subjects with good physical performance [7,10]. Second, the correlation between PFC activation and the dual-task cost on physical and cognitive performance in stroke patients would be different than that in healthy subjects. PFC activity of healthy subjects would correlate with cognitive dual-task cost, but that of stroke patients with hemiparesis would correlate with physical dual-task cost to prioritize motor demands. In order to test these hypotheses, we evaluated the correlation between PFC activity and dual-task cost when performing a calculation task while walking in

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healthy subjects and stroke patients. Understanding the role of PFC function in attention allocation during dual-task walking might reveal the neural mechanism for prioritization between cognitive and physical demands in patients with stroke.

2. Methods

2.1. Participants

A total of 14 stroke patients (12 men and 2 women; mean age, 61.1 ± 9.3 years; range, 36–72 years) and 14 healthy subjects (11 men and 3 women; mean age, 66.3 ± 13.3 years; range, 30–74 years) participated in this study. All participants were right-handed and had Mini-Mental State Examination (MMSE) performances well above the suggested dementia cutoff score of 24 [11]. Healthy subjects had no neurological abnormalities. In stroke patients, the inclusion criteria were: age > 20 years, presence of a single unilateral subcortical stroke, time since stroke onset > 6 months, and ability to walk independently using a T-cane and/or orthosis. The exclusion criteria were: presence of multiple stroke lesions, prefrontal cortex lesions, orthopedic disorders, cognitive deficits (MMSE < 25/30 points), and cortical stroke. The protocol was approved by the Ethics Committee of Tohoku University Graduate School of Medicine (reference no. 2014-1-829), and all subjects provided written informed consent.

2.2. Measurement of baseline cognitive and physical function

The Trail-Making Test (TMT) was performed to assess executive function [12]. The TMT is a two-part task (TMT-A and TMT-B) that evaluates the executive functions of cognitive flexibility and working memory. The Timed Up and Go Test (TUG) was performed to assess physical function [13], and the gait speed during a 10-m walk was measured.

2.3. Single and dual tasks

All participants were instructed to perform a calculation task while continuously walking at a comfortable pace on the floor, around a circle with a radius of approximately 2.5 m, as in a previous study [9]. Each block consisted of a 60 s calculation period and 60-s control period. The control period occurred first, during which the participant was instructed to repeat the numbers 1–10 in sequence. During the calculation period, the participant had to perform serial subtractions of 3, beginning with a random number between 100 and 199. Both the control period and calculation period were alternately repeated 3 times and ended at the 4th control period. The results of each calculation were spoken out loud, and the starting number was changed at 20 s intervals. Correct and incorrect responses were recorded using a voice recorder (RR-XP007™, Panasonic, Japan). Moreover, participants performed the calculation tasks while standing and walking in order to compare the calculation task performance between single and dual-task conditions. The order of the standing and walking conditions was counterbalanced. The mean values of the number of correct and mistaken responses in each condition were compared statistically.

2.4. Gait parameters

To evaluate gait performance, trunk linear accelerations were measured using an accelerometer. The accelerometer (Wireless Motion Sensor™, Sports sensing, Japan; size, 40 × 20 × 55 mm; weight, 35 g) was attached with a belt over the L3 spinous process. Acceleration data were recorded with a sampling frequency of 100 Hz. We used an adjustment application (LabVIEW™, National instruments, Japan) to synchronize the start time between the calculation task and the acceleration measurement. Acceleration magnitudes were obtained by calculating the root mean square of the acceleration data [14]. As in a previous study, we averaged the acceleration magnitude values across those calculated for the anteroposterior and vertical directions [9].

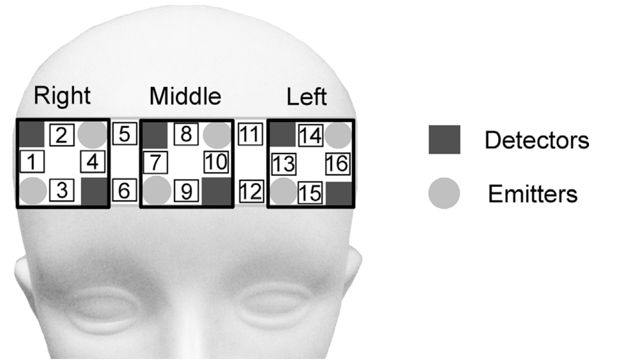

Fig. 1. Schematic representation of NIRS probes and channels.
The NIRS system used in this study consists of 6 emitters (gray circles) and 6 detectors (black squares), resulting in 16 source detector pairs called channels (white squares with channel numbers). The distance between the source and detector probe in each channel is set at 3.0 cm. Signals from the 4 channels over each region (the right PFC [No. 1–4], middle PFC [No. 7–10], and left PFC [No. 13–16]) were averaged.
NIRS, near-infrared spectroscopy; PFC, prefrontal cortex.

2.5. NIRS measurement

A 16-channel NIRS system (WOT™, Hitachi Corporation, Japan) was worn by the subjects to evaluate PFC activation during dual-task walking. A portable processing unit for controlling the optical topography measurements was connected to the probe unit via a flexible cable bundle. The processing unit sent the data to a personal computer that controlled the experiment through a wireless local area network. A schematic diagram of the NIRS probes and channels are shown in Fig. 1. The NIRS system used in this study consisted of 6 emitters and 6 detectors, which resulted in 16 channels, each consisting of 1 source-detector pair. The distance between the source and detector probes in a channel was set to 3.0 cm. In accordance with the international 10–20 system used in electroencephalography, the lowest probes were positioned along the Fp1–Fp2 line [9]. Changes in the concentrations of oxygenated hemoglobin (oxy-Hb) and deoxygenated hemoglobin (deoxy-Hb) were calculated using the absorbance change at 705 nm and 830 nm light wavelengths according to the modified Beer-Lambert law [15,16]. In a previous NIRS study, oxy-Hb appeared to be a more sensitive parameter for measuring blood flow [17]; hence, we used the change in oxy-Hb as an indicator of the changes in PFC activation. The personal computer emitted a sound to indicate when walking had commenced and to signal the beginning of the control and task periods.

2.6. NIRS data analysis

All participant data consisted of 3 task blocks. We defined an analysis block as the period from 40 s prior to calculation task onset in an experimental block to 20 s after calculation task completion. The sampling frequency for the NIRS data was 5 Hz. A moving-average filter with a time window of 5 s was applied. A band pass filter with a low pass (0.5 Hz) was applied to account for the effects of Mayer waves and high-frequency fluctuations, whereas that with a high pass (0.01 Hz) was used to account for baseline drift. A drawback of the NIRS method is the variability in the path length, which depends on the superficial scalp and tissue structure over the brain [18,19]. To avoid these problems, the oxy-Hb data from each channel was normalized via linear transformation, such that the mean ± standard deviation values of the oxy-Hb levels in the 5–15 s prior to the calculation task condition were 0 ± 1 arbitrary units (AU). This normalization also helped to compensate for the influence of differential path-length factors between participants and between cortical regions [20]. The NIRS data during