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Original Article

Effect of Trunk Solution® on hemodynamics in the supplementary motor area during walking

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Abstract. [Purpose] Humans keep their trunks vertical while walking. This defining characteristic is known as upright bipedalism. Research on the neural control of locomotion indicates that not only subcortical structures, but also the cerebral cortex, especially the supplementary motor area (SMA), is involved in locomotion. A previous study suggested that SMA may contribute to truncal upright posture-control during walking. Trunk Solution® (TS) is a trunk orthosis designed to support the trunk in decreasing the low back load. We hypothesized that the trunk orthosis might reduce the burden of truncal control on the SMA. The objective of this study was, therefore, to determine the effect of trunk orthosis on the SMA during walking. [Participants and Methods] Thirteen healthy participants were enrolled in the study. We measured the hemodynamics of the SMA during walking with functional near-infrared spectroscopy (fNIRS). The participants performed two gait tasks on a treadmill: (A) independent gait (usual gait) and (B) supported gait while wearing the TS. [Results] During (A) independent gait, the hemodynamics of the SMA exhibited no significant changes. During (B) gait with truncal support, the SMA hemodynamics decreased significantly. [Conclusion] TS may reduce the burden of truncal control on the SMA during walking.
Key words: Truncal upright posture control, Supplementary motor area (SMA), Trunk orthosis

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INTRODUCTION

Humans keep their trunk vertical while walking. This process is known as upright bipedalism and is a distinctive characteristic of humans[1)]. Research on the neural control of locomotion indicates that in addition to subcortical structures such as the midbrain, cerebellum, and basal ganglia, the cerebral cortex is involved in locomotion[2)]. Brain imaging techniques that can measure human brain activity during movement have shown that the supplementary motor area (SMA) is related to walking[3–5)]. We studied the hemodynamics in the SMA during walking, and revealed that the SMA may contribute to controlling truncal upright posture during walking[5)].

The Trunk Solution® (TS) (Trunk Solution Co., Ltd., Tokyo, Japan) is a trunk orthosis designed to support the trunk and decreases the low back load (Fig. 1). The TS has joints with springs that provide a resistive force to the backload and supports the trunk. It has been proven that wearing TS decreases the activity of the erector spinae muscle during level walking in healthy participants[8)].

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Fig. 1. Trunk Solution®. The Trunk Solution® has joints with springs and supports the trunk.

When the TS supports the trunk, the burden of controlling truncal upright posture on the SMA might be reduced. However, the effect of wearing TS on SMA has not yet been evaluated. The objective of the present study was to investigate the impact of wearing TS on SMA during walking. The hemodynamics of the SMA were measured. We hypothesized that when the trunk is supported during walking, SMA hemodynamics will decrease because the SMA does not need to work as usual to control truncal upright posture.

PARTICIPANTS AND METHODS

Thirteen healthy adults (12 males and one female; mean age ± standard deviation (SD), 25.1 ± 6.3 years) participated in this study. All participants provided written informed consent before participating in the study. All procedures were conducted in accordance with the Declaration of Helsinki, and the study was approved by the Ethics Committee of Niigata University of Health and Welfare (Approval number 1773-160902).

We used a functional near-infrared spectroscopy (fNIRS) (Spectratech OEG-17APD; Spectratech Inc., Tokyo, Japan) to measure SMA hemodynamics while participants performed gait tasks on a treadmill (IGNIO R-16 Alpen Co. Ltd., Nagoya, Japan). The fNIRS system emitted near-infrared light (two wavelengths: 840 nm and 770 nm) and detected the transmitted light. The sampling rate of the signals was 12.2 Hz (i.e., the time resolution was 0.0819 s). Changes in oxygenated hemoglobin (oxy-Hb) concentrations were measured based on the modified Beer–Lambert law[6)].

Twelve emission probes and 12 detection probes were set on a 3 × 8 pallet (yielding 37 channels) and positioned over Cz, according to the international 10/20 system, to cover the SMA area (Fig. 2). The interprobe distance was set at 3.0 cm. According to Okamoto et al.[7)], channels 16, 17, 19, 21, and 22 cover the SMA.

All participants performed two gait tasks on the treadmill: (A) independent gait (usual gait) and (B) supported gait by wearing the experimental version of the TS (Fig. 3). The temporal sequence of the tasks is illustrated in Fig. 4. A block design consisting of five repetitions of 40 s of gait and 40 s of rest was implemented. The treadmill speed was set at natural speed for each participant.

Oxy-Hb concentration was analyzed because it is related to brain activity[9–11)]. First, a bandpass filter (0.006–0.2 Hz) was used to remove high- and low-frequency noise and linear fitting was applied to correct the baseline drift. Linear fitting was computed between the mean of the 5-s period just before the gait condition and the mean of 30 to 35 s for the rest period. The average of five repetitions was then computed. These processing procedures are commonly used for fNIRS data[5, 12–14)], and channels with inappropriate signals were excluded. This process was performed for each channel and task of each participant.

Then, we determined the oxy-Hb value for the SMA by calculating the spatial average across channels 16, 17, 19, 21, and 22 (i.e., the regions of interest covering the SMA). This process was performed for each task of each participant.

Lastly, the oxy-Hb values for the two temporal phases were calculated: the rest phase and the walking phase. Each value was calculated as the temporal mean of a 5-s period. The oxy-Hb value for the rest phase was calculated as the mean of the 5-s period immediately before the gait period. The oxy-Hb value for the walking phase was calculated as the mean of the 30–35 s gait period. These periods were selected considering a delay of several seconds between the neural activity and hemodynamic response[15, 16)]. This process was performed for each task of each participant.

To detect any significant hemodynamic changes between the rest and walking phases, we performed paired t-tests between the rest and walking phases for all 13 participants. The SPSS software (ver. 22, IBM Corp., North Castle, NY, USA) was used for the analysis. Statistical significance was set at $p<0.05$.

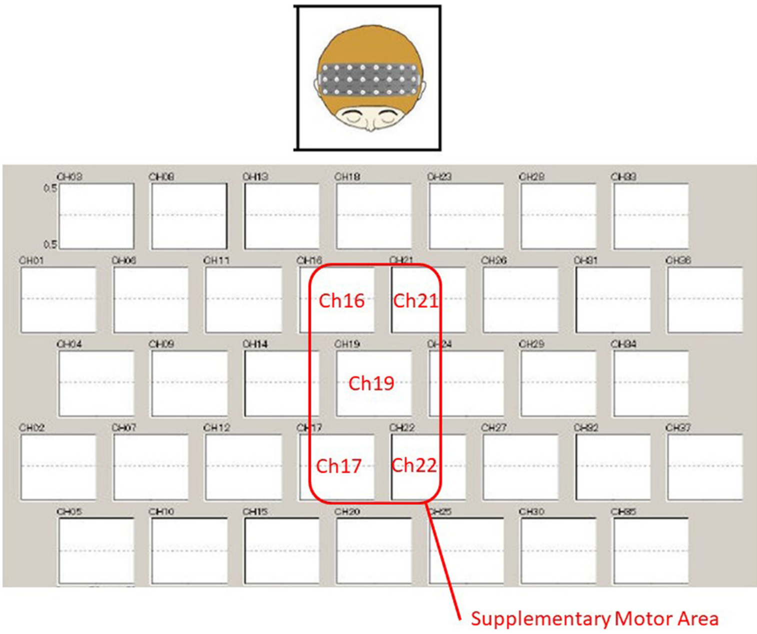

Fig. 2. Near-infrared spectroscopy probe settings. The supplementary motor area is covered by channels 16, 17, 19, 21, and 22. (Modified from a web page of Spectratech, Inc.; https://www.spectratech.co.jp/product/17apd/sen17apd.html).

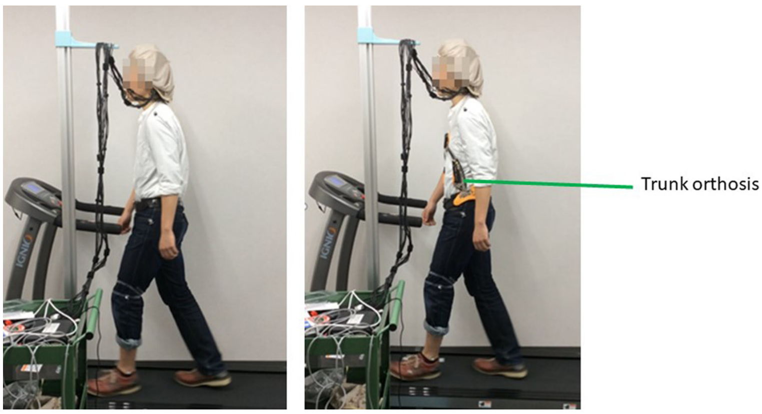

Fig. 3. Experimental setup.

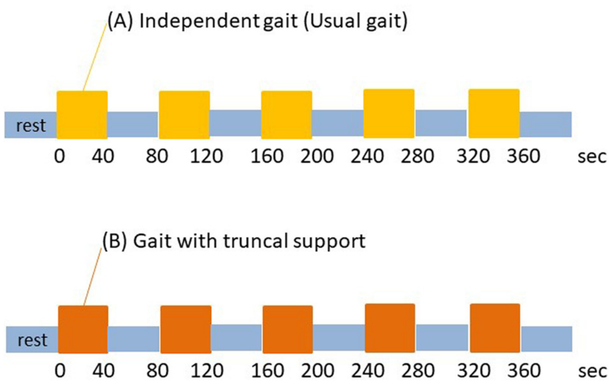

Fig. 4. Temporal sequence of the task design. A block design consisting of five repetitions of 40 s of gait and 40 s of rest was implemented.

RESULTS

Table 1 shows the oxy-Hb values during each task's rest phase and walking phase. In the (A) independent gait task, no significant changes occurred (p=0.183). In the (B) gait with truncal support condition, oxy-Hb values significantly decreased during the walking phase (p=0.025).

DISCUSSION

This study investigated hemodynamics in the SMA during walking using fNIRS in healthy participants. Each participant performed (A) an independent gait condition (usual gait) and (B) a gait with truncal support. There were no significant changes in SMA hemodynamics in the (A) independent gait condition. In contrast, in the (B) gait with truncal support condition, the SMA hemodynamics significantly decreased during walking.

Our previous study measured SMA hemodynamics during gait under vertical (i.e., upright) and horizontal trunk conditions[5]. In the vertical (upright) trunk condition, SMA hemodynamics exhibited no significant changes. In the horizontal trunk condition, the SMA hemodynamics significantly decreased. In the horizontal trunk condition in our previous study, the participants did not need to control upright trunk posture. Therefore, the results of our previous study suggest that the SMA may contribute to maintaining truncal upright posture during walking.

In the present study, (A) independent walking (usual upright walking) showed no significant changes in SMA hemodynamics. This result is consistent with the vertical (upright) trunk condition in our previous study[5]. The participants needed to control their upright trunk posture during walking, and we believe that basic activity of SMA is required. Therefore, the SMA hemodynamics did not decreased in the upright condition.

In the present study, (B) gait with truncal support showed that SMA hemodynamics decreased significantly. The orthosis we used supports the trunk and has been reported to decrease the erector spinae muscle activity during walking[8]. The participants did not need to control their trunk as they usually would. The burden of truncal posture control on the SMA may be reduced in (B) gait with truncal support. This may be the reason for decreased SMA hemodynamics in (B) gait with truncal support.

Upright bipedalism is characteristic of humans, and the SMA is involved in upright bipedalism. From our studies evaluating SMA hemodynamics during walking, the SMA may contribute to truncal upright posture control during walking. TS may reduce the burden of truncal control on the SMA during walking.

The limitation of this study is that we investigated only the immediate effect of wearing Trunk Solution®. In a future study, we will investigate the long-term effects of wearing Trunk Solution®. We intend to measure not only the hemodynamics of the brain but also the kinematics of the body, which may produce significant information about brain activity and body movement.

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Conflicts of interest

AY, HO: None to declare. JK and KM are shareholders and advisors of Trunk Solution Co., Ltd.

Table 1. Oxygenated hemoglobin of supplementary motor area for each task

Task	n	Rest phase		Walking phase	
		Mean	SD	Mean	SD
(A) Independent gait (usual gait)	13	0.000	0.000	−0.051	0.130
(B) Gait with truncal support	13	0.000	0.000	−0.066	0.093*

Mean and standard deviation (SD) of 13 participants (unit: mmoL/L × mm).
*p<0.05; p-values are for paired t-test between the rest and walking phases.

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