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CHANGES IN EVENT-RELATED POTENTIALS ASSOCIATED WITH POSTURAL ADAPTATION DURING FLOOR OSCILLATION

K. FUJIWARA,[a*] K. MAEDA,[b] M. IREI,[a] A. MAMMADOVA[a] AND N. KIYOTA[c]

[a] *Department of Human Movement and Health, Graduate School of Medical Science, Kanazawa University, 13-1 Takara-machi, Kanazawa 920-8640, Japan*

[b] *Department of Physical Therapy, Morinomiya University of Medical Sciences, 1-26-16 Nanko-kita, Suminoe-ku, Osaka 559-8611, Japan*

[c] *Department of Rehabilitation Science, Osaka Health Science University, 1-9-27 Tenma, Kita-ku, Osaka 530-0043, Japan*

Abstract—The event-related potential (ERP) mainly reflecting activation of the frontal lobe was measured during periodic floor oscillation, and changes in postural preparation and attention to the postural disturbance according to this adaptation were investigated. The experiment consisted of two tasks with eyes closed: adaptation to floor oscillation and finger flexion coinciding with the anterior and posterior reversals of oscillation. Subjects were 20 healthy young adults. They maintained a standing posture for 1 min (1 trial) on the force platform which oscillated in the anteroposterior direction at 0.5 Hz and an amplitude of 2.5 cm. ERP from a Cz electrode, activity of postural muscles and the center of foot pressure in the anteroposterior direction (CoPy) were analyzed. In the adaptation task, the speeds of CoPy fluctuation gradually decreased and reached a plateau between 4th and 14th trials, with inter-subject differences. Posterior postural muscles were activated in response to the anterior reversal of oscillation according to adaptation and also in the finger flexion task, with the largest activation of the gastrocnemius (GcM). A negative ERP peak was observed to occur locally around the anterior reversal of oscillation after adaptation. The peak ERP time had the strongest positive correlation with the peak activation time of the GcM, and the amplitude of the negative peak decreased with adaptation. In the finger flexion task, a negative ERP peak was observed around each target point. This negative peak was related to the anticipatory attention directed to the reversal point and to motor preparation for finger flexion. It is conceivable that the increasing negative ERP in the adaptation task reflects the dynamics of motor preparation and attention mainly for the anterior reversal, where the negative ERP peak is closely related to anticipatory information processing of somatosensory stimuli arising around the time of the reversal.

Key words: floor oscillation, event-related potential, sensory information, attention, anticipatory postural control.

INTRODUCTION

Periodic floor oscillation is useful to investigate postural control adaptability (Nardone et al., 2000; Fujiwara et al., 2007; Van Ooteghem et al., 2009; Schmid et al., 2011) because subjects can repetitively acquire feedback sensory information related to the balance disturbance. During floor oscillation in the anteroposterior direction, the largest perturbation occurs at the anterior and posterior reversals, thus postural preparation and attention directed to those reversal points are important issues.

During floor oscillation for 60 s or less with eyes closed, the lower leg muscles, especially the gastrocnemius (GcM), are important for postural control (Dietz et al., 1993; Buchanan and Horak, 1999; Corna et al., 1999; Schieppati et al., 2002). Three-minute trials of 0.6-Hz floor oscillation revealed that the center of foot pressure in the anteroposterior direction (CoPy) and muscle activities of the lower leg, especially the tibialis anterior (TA) adaptively changed (Schmid et al., 2011). Repetition of a 1-min trial with 0.5-Hz floor oscillation and eyes closed improves dynamic postural controllability by the 5th trial (total trial time: 5 min) (Fujiwara et al., 2006, 2007). Initially, GcM and TA were mainly activated around the anterior and posterior reversal points, respectively. However, as the adaptation advanced with trial repetition (> 3 min), TA burst activity became non-periodic or even disappeared, with predominant activation of GcM (Fujiwara et al., 1988), and the activation of posterior muscles in the thigh and trunk became more predominant than that of the anterior muscles (Fujiwara et al., 2006). Therefore, our hypothesis was that after sufficient adaptation, the activity of the anterior muscles around the posterior reversal will decrease or disappear, with the posterior muscles (especially GcM) activated around the anterior reversal.

Activation of the frontal lobe related to anticipatory postural control has been examined by slow brain potentials. Readiness potential (RP) increases negatively to the onset of muscle activity and reflects the state of

*Corresponding author. Tel: +81-76-265-2225; fax: +81-76-234-4219.
E-mail address: fujikatu@med.m.kanazawa-u.ac.jp (K. Fujiwara).
Abbreviations: AH, abductor hallucis; ANOVA, analysis of variance; BF, biceps femoris; C7, vertebra prominens; CC, cross-correlation coefficient; CNV, contingent negative variation; CoPy, center of foot pressure in the anteroposterior direction; CV, coefficient of variation; EEG, electroencephalogram; EMG, electromyogram; EOG, electrooculogram; ERP, event-related potential; ES, erector spinae; FDS, flexor digitorum superficialis; %FL, percentage distance from the heel in relation to foot length; GcM, gastrocnemius; HSD, honestly significant difference; LED, light-emitting diode; RA, rectus abdominis; rEMG, full-wave rectified electromyogram; RF, rectus femoris; RP, readiness potential; SD, standard deviation; Sol, soleus; TA, tibialis anterior.

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motor preparation (Kornhuber et al., 1969). Contingent negative variation (CNV) increases negatively toward the response signal (Walter, 1964) and is considered to reflect anticipatory attention to response signal and motor preparation (Brunia and van Boxtel, 2001). In addition, the CNV peak corresponds to a peak of anticipatory attention and/or onset of attentional shift to the output of a motor command (Macar and Vidal, 2002; Jacobs et al., 2008; Fujiwara et al., 2011). Thus, it would be difficult to clearly distinguish between the RP and CNV. On the other hand, a negative peak approximately 100 ms after transient floor translation (perturbation evoked potential) is considered to reflect the processes of sensory information related to the perturbation (Quant et al., 2004). In the present study using floor oscillation, event-related potentials (ERPs) such as the above-described potentials were measured together with muscle activity, CoPy, and joint movement. Considering the characteristics of muscle activity, our next hypothesis was that before adaptation, a negative ERP peak would be observed around either the anterior or posterior reversal, but after adaptation, the peak would be found mainly around the anterior reversal, with decreasing amplitude.

In order to clarify ERP components, as an additional experiment, subjects performed finger flexion in accordance with the posterior or anterior reversal of the floor oscillation while standing. As finger flexion has little effect on postural control, it is commonly used for directing attention to sensory information (Mochizuki et al., 2009). The third hypothesis was that the negative ERP peak would appear around the reversal points where subjects performed the finger flexion, and before the onset of muscle activation for finger flexion, as it reflects motor preparation for the finger flexion.

In this study, we investigated the changes in postural preparation and attentional allocation with adaptation during floor oscillation using ERP, and the relationship between ERP and biomechanical data, with the above-described working hypotheses.

EXPERIMENTAL PROCEDURES

Subjects

Subjects were 20 healthy young adults (12 men, 8 women). Mean age, height, weight, and foot length were 20.9 years (standard deviation (SD) = 3.0), 166.6 cm (SD = 8.0), 59.7 kg (SD = 9.9), and 24.6 cm (SD = 1.4), respectively. No subject had any history of neurological or orthopedic impairment. The experiment consisted of two tasks: adaptation to the floor oscillation (adaptation task), and a finger flexion task coinciding with the anteroposterior reversal of oscillation (finger flexion task). All subjects performed the adaptation task and 11 subjects (5 men, 6 women) performed the finger flexion task. Written informed consent was obtained from all subjects in accordance with the Declaration of Helsinki following an explanation of the experimental protocols. The study and protocols were approved by our institutional ethics committee.

Apparatus and data recording

A force platform (50 cm long and 50 cm wide, WA1001; WAMI, Tokyo, Japan) consisting of three load cells was used to record CoPy. An oscillation table (PW0198; Electric Control Group, Tokyo, Japan) with the attached force platform was oscillated sinusoidally at 0.5 Hz and with 2.5-cm amplitude in the anteroposterior direction (Fig. 1). A linear position sensor (LP10; Midori, Chikuma, Japan) was used to detect table oscillation and oscillation frequency was measured using a frequency counter (TR-5822; Advantest, Tokyo, Japan). Earplugs were worn to minimize auditory noise from the oscillating table because it was loud.

Ag–AgCl cup electrodes (8 mm in diameter) for electroencephalogram (EEG) recording were affixed to the scalp at Fz, Cz, and Pz in accordance with the International 10–20 system, and referred to linked ear lobes. A ground electrode was placed at Fpz. An electrooculogram (EOG) was recorded from a pair of electrodes placed above and below the left eye in order to monitor artifacts accompanying eye movement. Surface electrodes (P-00-S; Ambu, Ballerup, Demark) were used in a bipolar derivation in order to record surface electromyograms (EMGs) from the following muscles on the right side of the body: rectus abdominis (RA) at the level of the navel; erector spinae (ES) at the level of the iliac crest; rectus femoris (RF); the long head of biceps femoris (BF); TA; the medial head of GcM; soleus (Sol) and abductor hallucis (AH). The flexor digitorum superficialis (FDS) was recorded from the dominant hand in subjects who participated in the finger flexion task. The FDS is suitable for surface EMG recording because it is located at the surface layer of the forearm. After shaving and cleaning the skin with alcohol, electrodes were aligned along the major axis of each muscle, with an inter-electrode distance of approximately 3 cm. All electrode input impedance was reduced to $\leqslant 5$ kΩ. Signals from electrodes were amplified (EEG, $\times$40,000; EOG, $\times$4000; and EMG, $\times$4000) and band-pass filtered (EEG, 0.05–100 Hz; EOG, 0.05–30 Hz; and EMG, 5–500 Hz) using an amplifier (6R12; NEC-Sanei, Tokyo, Japan). The high-pass filter around 0.05 Hz is commonly used for recording slow brain potentials such as CNV (Jacobs et al., 2008) and RP (Colebatch, 2007), and includes sufficient frequency bandwidth to investigate the brain potential component that corresponds to floor oscillation at 0.5 Hz.

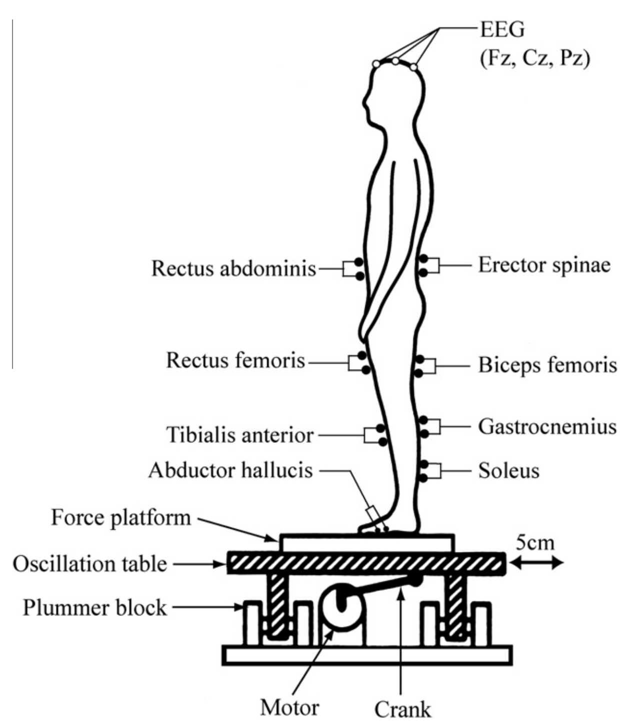

Fig. 1. Experimental setup. EEG, EMG and CoPy were recorded during floor oscillation.