Neuroscience Letters 490 (2011) 135–139

Contents lists available at ScienceDirect

Neuroscience Letters

journal homepage: www.elsevier.com/locate/neulet

Contingent negative variation and activation of postural preparation before postural perturbation by backward floor translation at different initial standing positions

Katsuo Fujiwara[a,*], Naoe Kiyota[a], Kaoru Maeda[b]

[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, Faculty of Health Science, Morinomiya University of Health Sciences, 1-26-16 Nanko-kita, Suminoe-ku, Osaka 559-0034, Japan

ARTICLE INFO

Article history:
Received 12 October 2010
Received in revised form 7 December 2010
Accepted 16 December 2010

Keywords:
Contingent negative variation
Postural preparation
Attention
Balance difficulty
Floor translation

ABSTRACT

We investigated the effects of balance difficulty on contingent negative variation (CNV) and postural preparation against perturbation. Thirteen subjects were perturbed by a backward floor translation (S2) after an auditory warning stimulus. To alter balance difficulty, subjects maintained standing posture from four initial positions before perturbation. The position of the center of pressure in the anteroposterior direction (CoPy) was expressed as a percentage distance of foot length (%FL) from the heel: 10%FL anterior to extreme backward leaning; quiet standing (QS); and 20%FL and 10%FL posterior to extreme forward leaning. CNV, CoPy, and electromyography (EMG) of the lower leg muscles were analyzed. Balance difficulty was represented by the relative distance of the forward peak position of CoPy after S2 from the QS position. Balance difficulty was higher with a more anterior initial position. The late CNV peaked just before S2 (latency: −76 to −306 ms), then started becoming small. CNV peak was earlier and larger with increasing balance difficulty. CoPy backward shift and a continuous EMG increase were observed as the strategy for postural preparation, and were significantly earlier (61 ms and 42 ms, respectively) than the CNV peak. CNV peak time correlated closely with onset times of CoPy backward shift ($r = 0.78$) and continuous EMG increase ($r = 0.71$). These findings suggest that as balance difficulty increases, attentional allocation to sensory information and/or postural preparation starts earlier just before the perturbation.

Transient floor translation has often been used for postural disturbance. Activities of postural muscles on electromyography (EMG) and displacement of the center of pressure in the anteroposterior direction (CoPy) have been analyzed as indices of automatic postural responses for a long time [2]. On backward floor translation, with more anterior initial standing position, CoPy shifts forward and reaches a forward critical point within the foot's supporting base. Thus, balance difficulty changes according to the initial standing position.

Anticipation of disturbance timings and preparation for floor translation is an important function [8]. Contingent negative variation (CNV), recorded by averaging the results of electroencephalography (EEG) between warning (S1) and response stimuli (S2) [18], is an appropriate value to evaluate the state of anticipation and preparation. In most CNV studies, the response task to S2 involved highly voluntary movements such as finger flexion [15] or shoulder flexion [5]. Conversely, postural control in response to transient floor translation is executed automatically. CNV was also reportedly induced using floor translation as S2, suggesting that cognitive and motor preparation processes resembling voluntary responses probably also exist in automatic postural responses [10]. CNV can be classified into early and late components, with late CNV considered to reflect the motor preparation process and anticipatory attention directed to S2 [1]. Amplitude of the late CNV increases with larger amounts of attention directed to S2 [1]. In floor translation, the amount of attentional allocation may increase with increased difficulty of maintaining postural balance, and thus reflects the changes in the late CNV.

In our previous study using the S1–S2 paradigm with arm movement responses to S2, relatively difficult prediction of S2 timing was found to result in CNV becoming smaller just before S2 [5]. This peak in CNV presumably indicates either a starting point of postural preparation or attentional allocation to objects other than S2. If the balance difficulty increases, the CNV change may start earlier before S2, to allow sufficient time for postural preparation. Similar CNV changes have been also reported in different cases, such as finger flexion performance before S2 [16], and when S2 was presented later than predicted timing [11]. How-

* Corresponding author. Tel.: +81 76 265 2225; fax: +81 76 234 4219.
E-mail address: fujikatu@med.m.kanazawa-u.ac.jp (K. Fujiwara).

0304-3940/$ – see front matter
doi:10.1016/j.neulet.2010.12.043

ever, those studies simply represented the beginning of motor initiation.

In the postural forward disturbance, slight backward shifts in CoPy and EMG activation just before the disturbance were observed as phenomena associated with preparatory postural control [8,13]. However, relationships between CNV and postural preparation have not been discussed and changes with balance difficulties still have not been investigated.

In this study, to vary balance difficulty, subjects maintained standing posture in different initial positions until the onset of backward floor translation (S2), and just before postural perturbation, the relationship between CNV and preparatory postural control were investigated using an S1–S2 paradigm.

Subjects comprised 13 healthy adults (6 men, 7 women). Mean ± standard deviation (SD) of age, height, weight, and foot length (FL) were 23.4 ± 4.9 years, 165.5 ± 11.1 cm, 58.5 ± 8.5 kg, and 24.6 ± 1.5 cm, respectively. No subject had any history of neurological or orthopedic impairment. Informed consent was obtained from all subjects following an explanation of the experimental protocols, which were approved by our institutional ethics committee.

A platform (FPA34; Electro-design, Japan) was used to measure CoPy. CoPy data were then sent to the following two devices: one computer (PC9801BX2; NEC, Japan) to inform CoPy position and another computer for analysis. The former received CoPy data via an A/D converter (PIO9045; I/O-Data, Japan) at 20 Hz with 12-bit resolution and could generate a buzzer sound when CoPy was located within ±1 cm of required position. CoPy position was calculated and shown as the percentage distance from the heel in relation to FL (%FL). The force platform was fixed to a handmade table that was movable horizontally in an anteroposterior direction by a computer-controlled electric motor (VLA-ST-60-60-0300; THK, Japan). Direction, velocity, and amplitude of platform movement were adjusted using CuteyWave II software (Sanmei-Denshi, Japan). S1 was an auditory stimulus delivered via earphones, with frequency, intensity, and duration of 2000 Hz, 60 dB, and 50 ms, respectively. S2 was a transient backward floor translation (amplitude, 5 cm; velocity, 20 cm/s) [17]. Onset of translation was detected by an accelerometer (AG-2GB; Kyowa, Japan) fixed to the force platform.

Ag–AgCl cup electrodes (diameter, 8 mm) for recording EEG 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. Electrooculography (EOG) was recorded from a pair of electrodes placed above and below the left eye. To fix eye position, subjects were instructed to gaze at a fixation point presented on an Eye-trek face-mounted display (FMD011F; Olympus, Japan). Surface electrodes (M-00-S; Medicotest, Demark) were used in bipolar derivation to record EMG of the following muscles on both sides: tibialis anterior (TA); medial head of gastrocnemius (GcM); soleus (SOL); and abductor hallucis (AH). The electrodes were placed on both sides of the body with an inter-electrode distance of about 2 cm for AH and about 3 cm for the other muscles. Electrode input impedance was <5 kΩ. Signals from electrodes were amplified (EEG, ×40,000; EOG, ×4000; EMG, ×4000) and band-pass filtered (EEG, 0.05–100 Hz; EOG, 0.05–30 Hz; EMG, 5–500 Hz) using an amplifier (6R12; NEC-Sanei, Japan). For subsequent analyses, all electrical signals were sent to a computer (PC-9281V233; NEC, Japan) via an A/D converter (ADA16-32/2(CB)F; Contec, Japan) at 1000 Hz with 16-bit resolution.

All measurements were taken while subjects were standing barefoot, with feet 10 cm apart and parallel on the force platform. Mean CoPy position was initially measured for 10 s while subjects maintained a quiet standing (QS) posture with the upper limbs crossed in front of the chest. Mean values for the five trials were adopted as the QS position. Next, mean CoPy position during an extreme forward leaning (EFL) posture was measured twice. The subject gradually leaned forward from QS more than 5 s, pivoting at the ankles with the rest of the body kept aligned, and then maintained this EFL posture for 3 s. The most anterior CoPy position of the two trials was adopted as the EFL position. A similar procedure was used to measure CoPy position at an extreme backward leaning (EBL) position, in which subjects leaned the body backward.

Next, subjects performed a stance maintenance task on the platform. Until the onset of backward floor translation (S2), subjects maintained the standing posture within a range of ±1 cm in the following CoPy positions (initial standing positions) by pivoting the body at the ankles: 10%FL anterior to EBL position (EBL + 10); QS position (QS); and 20%FL (EFL-20) and 10%FL (EFL-10) posterior to EFL position (Fig. 1A). Each initial position was presented by a buzzing sound for at least 3 s. S1 was randomly presented 1–2 s after the experimenter stopped the buzzing sound, then S2 started 2 s after S1. Subjects were asked to avoid changing foot position or falling in response to S2.

To familiarize subjects with the task, 10 practice trials were performed in each initial position. Next, the experimental block for an initial position was conducted. For each block, a set of 10 trials was repeated until 20 artifact-free trials were obtained, with 3-min seated rest between each set. Trials were excluded if eye blinks or movement artifacts (voltage at EOG or any EEG electrode exceeding ±100 μV) occurred between 500 ms before S1 and S2, if foot position changes were identified before and after S2, or if deviation of CoPy over ±1 cm from the initial position was noted before S2. Mean frequency of excluded trials was 21.1% in EBL + 10, 25.2% in QS, 21.5% in EFL-20, and 32.3% in EFL-10, showing no significant difference between initial standing positions. The first experimental block was performed at QS, and then the order of blocks in other positions was randomized for the subject.

All data were analyzed using BIMUTAS II software (Kissei Comtec, Japan). For EEG data, mean amplitude for the 500-ms period before S1 was used as a baseline. EMG data were full-wave rectified. Waveforms of CoPy, EEGs, and EMGs from 500 ms before S1 to 3000 ms after S2 were then averaged for each condition. EMG waveforms recorded from left and right sides of the body were averaged.

Forward peak position of CoPy after S2 was identified to evaluate the magnitude of disturbance. Distance between the forward peak and QS positions relative to that between the QS and EFL positions was calculated (perturbation ratio). Late CNV was maximal at Cz in all initial positions. Waveforms recorded from Cz were therefore analyzed. Averaged EEG waveforms between S1 and S2 were 4-Hz low-pass filtered. Late CNV typically peaked before S2, then started becoming small (Fig. 1B). The peak of late CNV (CNV peak) was identified in the 1000-ms period before S2. CNV peak amplitude was shown as a positive value when the potential was negative, and CNV peak time to S2 was shown as a negative value when the peak preceded S2. CNV decrease prior to S2 was measured by calculating the difference between amplitudes of CNV peak and S2.

To investigate changes in CoPy deflection and EMG activation before S2 corresponding to CNV peak, averaged waveforms of CoPy and EMG between S1 and S2 were 4-Hz low-pass filtered. Observing these waveforms in EFL − 10 visually, the following CoPy shifts were recognized around CNV peak in some subjects with a clear CNV decrease prior to S2 (Fig. 1B(a)): either (1) as CoPy moved forward, then shifted backward toward S2; or (2) as CoPy shifted backward steeply toward S2. These shifts were preceded by EMG activation for most subjects. In subjects without such CoPy shifts, continuous EMG increase of postural muscles (GcM, SOL, and AH) was found around CNV peak (Fig. 1B(b)). These changes in each initial position were identified for subjects with CNV decrease prior to S2 above 5% of the CNV peak amplitude, as follows. When the mean speed of CoPy between the onset of CoPy backward move-