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Research Report

Cortical activity prior to predictable postural instability: Is there a difference between self-initiated and externally-initiated perturbations?

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ARTICLE INFO

Article history:
Accepted 28 April 2009
Available online 5 May 2009

Keywords:
Balance
Cortical
EEG
Postural set
Human

ABSTRACT

Previous work has revealed pre-perturbation cortical activity linked to predictably-timed perturbations to upright stability. Because individuals rely on the ability to anticipate perturbations for independent mobility, we sought to determine whether perturbation-evoked cortical potentials elicited by voluntarily-initiated external perturbations were dissociable from those elicited by externally-cued perturbations. Postural instability was evoked under three experimental conditions: cued external perturbations (EXT-CUE), cued self-initiated perturbations (SELF-CUE), and un-cued self-initiated perturbations (SELF-NO CUE). All conditions were characterized by comparable pre-perturbation slow-wave potentials initiated 1536.83 ± 44.94 ms prior to perturbation onset, measuring 11.24 ± 0.94 μV in amplitude. There were no differences in pre-perturbation cortical activity across tasks. Post-perturbation N1 potentials were also evoked, reaching peak amplitude at 132.63 ± 3.40 ms following perturbation onset. The potentials were significantly larger in the EXT-CUE (17.08 ± 2.99 μV) condition than both the SELF-CUE (11.98 ± 2.53 μV) and SELF-NO CUE conditions (9.24 ± 1.79 μV). There were no significant differences across tasks for measures of tibialis anterior muscle activity prior to or following perturbation onset, nor were there significant differences in centre of pressure excursion amplitude across tasks. This study highlights that despite using different mechanisms to initiate temporally predictable perturbations to upright stability, pre-perturbation cortical events with similar spatio-temporal characteristics and magnitude are evoked, signalling consistency in the cortical processes that optimize compensatory postural responses which are independent from the cues that inform the onset of postural instability. These findings enhance the understanding of cortical involvement in postural control.

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Abbreviations: ANOVA, analysis of variance; CNS, central nervous system; COP, centre of pressure; EEG, electroencephalography; EMG, electromyography; iEMG, integrated electromyography; TA, tibialis anterior

0006-8993/$ – see front matter
doi:10.1016/j.brainres.2009.04.050

1. Introduction

Recent studies have emphasized the involvement of cortical activity in the control of postural stability (for review, see Maki and McIlroy, 2007). In human studies, there is convincing evidence of cortical activity following the onset of perturbations that evoke compensatory balance reactions (Dietz et al., 1984; Duckrow et al., 1999; Quant et al., 2004b; Adkin et al., 2006; Mochizuki et al., 2008b). In addition, recent studies have revealed pre-perturbation cortical activity when the timing of perturbations to stability is predictable in onset (Adkin et al., 2008; Jacobs et al., 2008; Mochizuki et al., 2008b). While successfully responding to truly unexpected perturbations to stability in the real-world environment is essential to the prevention of falls and in ensuring safe, independent mobility, individuals also rely heavily on the capacity to anticipate perturbations. Preparing the central nervous system (CNS) for upcoming perturbations to stability represents an important aspect of everyday behaviour because self-initiated movements are a common source of perturbations to upright stability. The current work is focused on providing insight into cortical contributions to CNS preparations to successfully control compensatory balance reactions.

Compensatory balance responses, while evoked by perturbations, are modified by changes in postural set, which reflect alterations in CNS gain prior to the onset of an upcoming perturbation and are driven by past experience and contextual information (Jacobs and Horak, 2007). Successful and appropriate calibration of postural set is proposed to be an essential element in generating efficient compensatory balance reactions (Jacobs and Horak, 2007). These changes in postural set are most readily observed when the timing of the onset of the perturbation is predictable; such predictability may be derived from the presence of external cues warning of an imminent bout of instability or by the self-initiation of a postural perturbation by a focal movement. However, the presence of anticipatory motor activation prior to the onset of postural instability that is common to both the predictable perturbations and the voluntary movements that evoke balance reactions challenges the examination of the cortical activity associated with postural instability. In order to explore the cortical correlates of postural set, it is important to minimize the confounds introduced by either the motor preparation for focal, destabilizing motor acts or by anticipatory postural muscle activation prior to the onset of a perturbation, as these events themselves are likely to elicit preparatory changes in cortical activity. In a previous paper, Mochizuki et al. (2008b) demonstrated that pre- and post-perturbation cortical activity could be elicited when individuals used a computer mouse to initiate an external perturbation to stability. It was hypothesized that pre-perturbation cortical activity was associated with changes in postural set, and not with the motor events that initiated the perturbation. This was confirmed by the absence of cortical activity when the button presses did not initiate postural instability. Despite these findings, questions remained as to whether the CNS processes self-initiated external perturbations differently than those whose timing could be predicted from external cues and whether these differences could be identified in the spatio-temporal parameters of perturbation-evoked cortical potentials. Identifying the differences in the cortical activity associated with self-initiated external perturbations to stability from that associated with externally-cued external perturbations to stability is an important step in understanding of the role of the cortex in balance control.

Differences in the spatio-temporal parameters of pre- and post-perturbation cortical activity would identify differences in either the preparation for or detection and interpretation of the threat of instability. While pre-perturbation cortical activity reflects changes in postural set, post-perturbation cortical potentials (i.e. the N1 potential, a large negativity evoked 100–150 ms post-perturbation) represent cortical involvement in error detection (Adkin et al., 2006) and scale in amplitude with the perceived consequence of postural instability (Adkin et al., 2008). Of particular importance is the evidence showing that despite being evoked by perturbations with identical characteristics (i.e. direction and amplitude), the amplitude of the N1 differs significantly when the conditions under which the perturbations are delivered are modified. It has been shown that factors such as predictability (Mochizuki et al., 2008b) influence N1 amplitude. Because the N1 amplitude is contextually mediated; that is, influenced by some task conditions such as stimulus predictability even when perturbation amplitude remains constant, they may also provide insight into pre-perturbation postural state. For example, the N1 may provide information about the cortical processes involved in the calibration of postural set for self-initiated and temporally predictable, externally generated perturbations or the interaction between preparatory and reactive cortical events.

Although the longer-term objective is to identify the unique cortical contributions to both elements of pre-perturbation control, namely, 1) adjustments in postural set and 2) planning and generating anticipatory balance responses, the goal of this study was to determine whether pre-perturbation cortical activity was dependent on the type of cues that signal the onset of postural instability. More specifically, this study examined the cortical events associated with both self-initiated perturbations and in temporally predictable perturbations that were not initiated by the individual. It was hypothesized that both self-initiated and externally-cued perturbations, in the absence of anticipatory motor activity, would be characterized by pre-perturbation activity with similar spatio-temporal parameters. In addition, it was proposed that the amplitude of the post-perturbation N1 potential would be similar in amplitude and timing for externally-cued and self-initiated perturbations in light of the pre-perturbation setting of CNS state in advance of the applied perturbation. Portions of this paper have been presented in abstract form (Mochizuki et al., 2008a).

2. Results

Of the ten participants initially recruited, data from two participants were excluded because of a high number of trials displaying anticipatory muscle activity. For these participants >80% of trials across all three conditions were classified as having anticipatory tibialis anterior (TA) electromyographic