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PERFORMANCE OF A CONCURRENT COGNITIVE TASK MODIFIES PRE- AND POST-PERTURBATION-EVOKED CORTICAL ACTIVITY

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Abstract—Preparation for postural instability engages cortical resources that serve to optimize compensatory balance responses. Engagement of these cortical resources in cognitive dual-task activities may impact the ability to appropriately prepare and optimize responses to instability. The purpose of this study was to determine whether cognitive dual-task activities influenced cortical activity preceding and following postural instability. Postural instability was induced using a lean-and-release paradigm in 10 healthy participants. Perturbations were either temporally predictable (PRED) or unpredictable (UNPRED) and presented with (COG) or without a cognitive dual-task, presented in blocks of trials. The electroencephalogram was recorded from multiple frontal electrode sites. EEG data were averaged over 25–35 trials across conditions. Area under the curve of pre-perturbation cortical activity and peak latency and amplitude of post-perturbation cortical activity were quantified at the Cz site and compared across conditions. Performance of the concurrent cognitive task reduced the mean (SE) magnitude of pre-perturbation cortical activity in advance of predictable bouts of postural instability (PRED: 18.7(3.0) mV ms; PRED-COG; 14.0(2.3) mV ms). While the level of cognitive load influenced the amplitude of the post-perturbation N1 potential in the predictable conditions, there were no changes in N1 with a cognitive dual task during unpredictable conditions (PRED: −32.1(3.2) μV; PRED-COG: −50.8(8.4) μV; UNPRED: −65.0(12.2) μV; UNPRED-COG: −64.2(12.7) μV). Performance of the cognitive task delayed and reduced the magnitude of the initial gastrocnemius response. The findings indicate that pre- and post-perturbation cortical activity is affected by a cognitive distractor when postural instability is temporally predictable. Distraction also influences associated muscle responses. © 2017 IBRO. Published by Elsevier Ltd. All rights reserved.

Key words: balance, EEG, preparation, dual-task.

INTRODUCTION

Following a disturbance to postural stability, humans generate rapid compensatory responses to prevent falling (Maki and McIlroy, 1997). These strategies aim to restore the position of the center of mass to within the base of support. Compensatory responses are contextually appropriate; that is, they scale to the magnitude of the perturbation and are specific to the real-time demands of the task. While this level of sensitivity implies an important role for processing of somatosensory information, other factors like environment (Adkin et al., 2000; Carpenter et al., 2001), state of the central nervous system (Horak et al., 1989), and attention (Rankin et al., 2000; Teasdale and Simoneau, 2001; Norrie et al., 2002) also play a role in determining and optimizing the appropriate response. The involvement of these other factors on the optimization of balance responses supports the position that the maintenance of balance is not a product of simple, autonomous motor output. Rather, it is a more complex program, generally performed under dual- or multi-task conditions, which relies on various sensory, motor, and cognitive resources.

To quantify the utilization of central nervous system resources that are available during balance recovery, contemporary research has examined activity in the cerebral cortex that precedes or follows postural instability (i.e. the instance when the center of mass falls outside of the base of support). Studies utilizing electroencephalography (EEG) have identified cortical potentials (event-related potentials, ERPs) including the P1, N1, and P2 (Quant et al., 2004b, 2005), which are time-locked to balance-perturbing stimuli. The most widely studied of these potentials, the N1, has been hypothesized to represent different aspects of compensatory balance control, including (1) the sensory processing of the balance disturbance (Dietz et al., 1984); or (2) a type of error detection mechanism, whereby N1 amplitude is reflective of the magnitude of difference (i.e., the error)

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between expected and actual events (Adkin et al., 2008). Based on source localization of the generators of the N1, namely the supplementary motor area, recent work has proposed that the N1 represents the generation of a motor plan to coordinate the later phases of the compensatory balance response (Marlin et al., 2014).

Inferences regarding the allocation of cortical resources in balance control are also derived from characterizations of the cortical activity associated with preparation for temporally and directionally predictable postural perturbations (Maeda and Fujiwara, 2007; Jacobs et al., 2008; Mochizuki et al., 2008). This pre-perturbation cortical activity may be linked to expectation and/or central set, and thus representative of the preparatory activity of the central nervous system in the face of imminent instability. For instance, the magnitude of the N1 and corresponding compensatory response scale to the presence of pre-perturbation cortical activity, with lower amplitude responses observed in temporally predictable versus temporally unpredictable perturbations (Jacobs et al., 2008; Mochizuki et al., 2008). Other work has expanded this evidence, demonstrating that pre-perturbation cortical activity scales to the magnitude of the expected perturbation, while defaulting to a ‘worst case scenario’ when the magnitude of the expected perturbation is unknown (Mochizuki et al., 2010).

One potential modifier of cortical capacity in preparation or response to postural instability is cognitive load. Performance of a cognitive task while concurrently being exposed to unpredictable balance perturbations attenuates N1 amplitude and concomitantly increases the magnitude of the compensatory balance response (Quant et al., 2004a; Little and Woollacott, 2014). This observation has been attributed to the ‘gating’ of sensory information; that is, the concurrent cognitive task diverts cognitive and attentional resources away from the balance disturbance, thereby reducing the cortical activity related to the unattended modality. Similarly, it is possible that a cognitive dual task that is engaged while preparing for predictably timed instability would also shift resources away from the cues that are required to optimize the postural response; however, there is no empirical evidence that this occurs.

Based on the current evidence, pre- and post-perturbation cortical activity may represent a process whereby the central nervous system increases gain (pre-) to optimize the compensatory response and then evaluates (post-) the response. If both the pre- and post-perturbation activity measured by EEG reflects the resources available to attend, prepare for, and respond to instability (in a general sense), then task-dependent shifting of the proportion of pre- and post-perturbation activity may reflect differences in levels of attention, preparation, and response output required in each condition. Alternatively, if one considers the time-varying changes in preparatory and evaluative EEG to represent extracellular activity in different nodes of a distributed cortical network (Nagai et al., 2004; Marlin et al., 2014) then one can infer task-dependent differences in activity in the different nodes of a postural attention-preparation-response network.

To further investigate this process, this study asks the question: if pre-perturbation cortical activity is a cognitive process linked to expectation/central set, does a reduction in the availability of cognitive resources through the addition of a secondary cognitive task alter both pre- and post-perturbation cortical activity? Through examination of cortical potentials resulting from temporally predictable and unpredictable balance perturbations under single- (perturbation only) and dual-task (perturbation + cognitive task) conditions, we hypothesized that, compared to the ‘perturbation only’ conditions, N1 amplitude would be larger for the dual-task conditions. From this perspective, we proposed that engaging in the dual-task would lead to an increased need to re-direct cortical resources toward engaging a motor plan for the later phases of the compensatory response. Moreover, we hypothesized that concurrent performance of the cognitive task would result in a reduction of the pre-perturbation cortical activity.

METHODOLOGY

Participants

Twenty-six participants agreed to participate in this study. Eight participants (five male, 28.1 ± 7.5 years, 174.8 ± 11.2 cm, 76.2 ± 16.2 kg) participated in pilot testing of the cognitive task only, while eighteen participants completed the full study. Owing to technical issues with data collection or exclusion from subsequent analysis due to artifact or anticipatory postural activity (see methods below), data from eight participants were removed (five male, 26.3 ± 3.5, 154.4 ± 30.5 cm, 69.3 ± 5.0 kg), leaving ten participants (four male, 27.7 ± 7.7 years, 171.2 ± 6.9 cm, 68.7 ± 11.4 kg) included in the final analysis of the full study. All participants were free of neuromuscular disorders (as determined by questionnaire during initial screening) and each provided written, informed consent prior to the onset of the study. The study was conducted with approval from the Research Ethics Board at the Toronto Rehabilitation Institute.

Data acquisition

Electroencephalography: Electroencephalographic (EEG) signals were obtained using a 32-channel electrode cap (Quik-Cap, Neuroscan, El Paso, TX, USA) based on the International 10-20 System. Data were collected from the Fz, FCz, Cz, CPz, Pz, C3, C4, FP1 and FP2 electrode sites. The impedance for all channels was maintained below 5 KΩ (confirmed at the start of each condition) and linked mastoids were used as reference. Electroculographic data (EOG) were obtained using four Ag-AgCl electrodes adhered using an adhesive ring, with one superior and one inferior to the left eye, and one just lateral to the left and right eye. EOG data were used in post-processing to remove artifacts attributable to eye blinks. EEG and EOG signals were sampled at 1000 Hz, filtered (DC-300 Hz) online using a NuAmps amplifier (Neuroscan, El Paso, USA), and stored for offline analysis.

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