Human Movement Science 50 (2016) 62–72

Contents lists available at ScienceDirect

Human Movement Science

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

Full Length Article

Higher order balance control: Distinct effects between cognitive task and manual steadiness constraint on automatic postural responses

Daniel Boari Coelho, Catarina Bourlinova, Luis Augusto Teixeira *

Human Motor Systems Laboratory, School of Physical Education and Sport, University of São Paulo, 05508-030, Brazil

ARTICLE INFO

Article history:
Received 24 May 2016
Revised 9 September 2016
Accepted 20 October 2016
Available online 24 October 2016

Keywords:
Perturbed posture
Stance perturbation
Postural control
Postural reactions
Multitasking

ABSTRACT

In the present experiment, we aimed to evaluate the interactive effect of performing a cognitive task simultaneously with a manual task requiring either high or low steadiness on APRs. Young volunteers performed the task of recovering upright balance following a mechanical perturbation provoked by unanticipatedly releasing a load pulling the participant's body backwards. The postural task was performed while holding a cylinder steadily on a tray. One group performed that task under high (cylinder' round side down) and another one under low (cylinder' flat side down) manual steadiness constraint. Those tasks were evaluated in the conditions of performing concurrently a cognitive numeric subtraction task and under no cognitive task. Analysis showed that performance of the cognitive task led to increased body and tray displacement, associated with higher displacement at the hip and upper trunk, and lower magnitude of activation of the GM muscle in response to the perturbation. Conversely, high manual steadiness constraint led to reduced tray velocity in association with lower values of trunk displacement, and decreased rotation amplitude at the ankle and hip joints. We found no interactions between the effects of the cognitive and manual tasks on APRs, suggesting that they were processed in parallel in the generation of responses for balance recovery. Modulation of postural responses from the manual and cognitive tasks indicates participation of higher order neural structures in the generation of APRs, with postural responses being affected by multiple mental processes occurring in parallel.

1. Introduction

Situations in which one performs more than one task simultaneously usually lead to degraded performance of at least one of the tasks. That interference has been largely reported in the performance of voluntary dual tasks (see Pashler, Johnston, & Ruthruff, 2001, for a review), with interference being theorized to raise from the competition among the processing resources required by each individual task for the limited attentional capacity (Kahneman, 1973). An issue of interest on this matter is the extent to which parallel performance of a task requiring attention affects the generation of automatic postural responses (APRs). Analysis of different dimensions of APRs to unanticipated perturbations of balance has shown that performance of a mental task while receiving a perturbation disturbs balance recovery. Rankin, Woollacott, Shumway-Cook, and

---

* Corresponding author at: Av. Prof. Mello Moraes, 65, São Paulo, SP 05508-030, Brazil.
E-mail addresses: daniboari@usp.br (D.B. Coelho), bourlinova@usp.br (C. Bourlinova), lateixei@usp.br (L.A. Teixeira).

http://dx.doi.org/10.1016/j.humov.2016.10.008
0167-9457/

Brown (2000) evaluated the effect of performing a mental numeric subtraction task on feet-in-place postural responses to abrupt unanticipated backward displacement of the basis of stance support. They found that mental involvement with the cognitive task led to reduced magnitude of muscular activation in the late components of the postural response. Further investigation has shown that concurrent performance of a cognitive task with the generation of postural feet-in-place responses to a mechanical perturbation also leads to increased amplitude of displacement of the center of pressure under the feet (Little & Woollacott, 2014; Little & Woollacott, 2015; Norrie, Maki, Staines, & McIlroy, 2002). In conditions in which a step was allowed as a response for the balance perturbation, concurrent performance of a cognitive task was found to affect stepping kinematics (Brown, Shumway-Cook, & Woollacott, 1999), and to induce delayed onset and reduced magnitude of muscular activation for stepping initiation (Brauer, Woollacott, & Shumway-Cook, 2002). These results suggest that neural structures generating APRs share attentional resources with those used to produce pure cognitive operations (cf. Kahneman, 1973), leading to impaired postural responses to balance perturbation in situations requiring concurrent use of attentional resources to perform a cognitive task.

Neurophysiological support for the notion that APRs require higher order processing resources has been provided by means of measurements of cerebral cortex activity in response to postural perturbations while performing a task demanding attention. Quant, Adkin, Staines, and McIlroy (2004) found that performance of a manual tracking task led to lower magnitude of the cortical N1 response (the first negative peak after perturbation onset) in electroencephalographic recordings. That alteration of the cortical response in the dual task condition was associated with higher magnitudes of center of pressure displacement and increased muscular activation. Similar effects were found in the cortical and balance stability measurements in APRs while performing a visual working memory task (Little & Woollacott, 2015). These findings support the notion that APRs require attentional resources to be appropriately executed. Although preliminary findings have suggested that early cortical activation following balance perturbation is associated with sensory processing (Dietz, Quintern, Berger, & Schenck, 1985; Quant, Adkin, Staines, Maki et al., 2004; Quant, Adkin, Staines, & McIlroy, 2004) or error detection (Adkin, Quant, Maki, & McIlroy, 2006), more recent evidence has shown that the locus of N1 is at the supplementary motor area (Ferraye et al., 2014; Fujimoto et al., 2014; Marlin, Mochizuki, Staines, & McIlroy, 2014; Mierau, Hulsdunker, & Struder, 2015) and that N1 amplitude is correlated with magnitude of postural sway and muscular activation (Mierau et al., 2015). Participation of the supplementary motor area in postural responses may be associated with organization and control of the evoked balance reactions to recover a stable upright posture following a perturbation (see Bolton, 2015; Maki & McIlroy, 2007, for reviews on cerebral cortex participation in APRs).

The aforementioned findings suggest that performance of a concurrent cognitive task leads to impoverished postural responses to an unanticipated balance perturbation. Performance of a concurrent manual task requiring positional hand steadiness, conversely, has been found to induce adaptive postural responses to perturbed balance. The seminal experiment showing this effect was conducted by Marsden, Merton, and Morton (1981) by comparing postural responses to a mechanical perturbation of upright balance while performing manual tasks with different provision of and constraint on postural stability: gripping a stable support (providing increased balance stability), gripping an unsupported handle (neutral, neither providing nor requiring increased balance stability), or holding a cup of tea (requiring increased balance stability). Results showed that activation of the extensor muscles of the grasping arm in response to postural perturbation was tailored for the specific task characteristics, with the long-latency reflex being activated in the condition of gripping the stable support but not when gripping the unsupported handle. Distinct postural responses were observed when holding the teacup, with the long-latency reflex being reversed and then favoring the maintenance of a stable position of the hand to keep the tea inside the cup. From these results, a functional integration between postural and supra-postural tasks becomes apparent, with posture-related sensory feedback triggering different APRs to attend the required balance stability to perform optimally the manual task. This issue has been readdressed more recently by evaluating APRs to unanticipated displacement of the basis of support while holding a tray (de Lima, de Azevedo Neto, & Teixeira, 2010). Manual steadiness constraint was manipulated by placing a cylinder with its round side down (high stability constraint) versus holding an empty tray (low stability constraint). These tasks were performed either in the context of certainty or uncertainty of direction of basis of support displacement. Results revealed that high manual task constraint induced lower angular motion at the hip following perturbation, dampening upper trunk displacement. Additionally, combination of certainty about perturbation direction and high manual task constraint led to a shorter delay of muscular activation onset. Those postural responses were associated with diminished displacement of the tray following balance perturbation, favoring maintenance of the cylinder at a steady position. Further investigation employing a similar experimental strategy (cylinder's round versus flat side down) corroborated the effect of manual task constraint on APRs in healthy older individuals (de Lima-Pardini et al., 2014), while modulation of postural responses from manual task constraint has been shown to be altered in individuals suffering from Parkinson's disease (de Lima-Pardini et al., 2012). As in this dual task context manual steadiness is determined by complex interactive torques applied at different joints to compensate for the postural perturbation (cf. Kim, Atkeson, & Park, 2012; Park, Horak, & Kuo, 2004), it seems that APRs are modulated as a function of a task-level variable representing an abstract global motor goal (Safavynia & Ting, 2013; Welch & Ting, 2014) as dictated by the required manual steadiness (de Lima et al., 2010). Additional research has shown that the long latency reflex component of a response to an unanticipated arm position perturbation is scaled by feedback mechanisms according to accuracy (Kurtzer, Crevecoeur, & Scott, 2014) and urgency (Crevecoeur, Kurtzer, Bourke, & Scott, 2013) constraints imposed by the task aim, taking into consideration inter-joint dynamics of the corrective movement (Nashed, Kurtzer, & Scott, 2015; Pruszynski, Kurtzer, & Scott, 2011). This optimal feedback control in response