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Full Length Article

How providing more or less time to solve a cognitive task interferes with upright stance control; a posturographic analysis on healthy young adults

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A R T I C L E I N F O

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A B S T R A C T

Contrasted postural effects have been reported in dual-task protocols associating balance control and cognitive task that could be explained by the nature and the relative difficulty of the cognitive task and the biomechanical significance of the force platform data. To better assess their respective role, eleven healthy young adults were required to stand upright quietly on a force platform while concomitantly solving mental-calculation or mental-navigation cognitive tasks. Various levels of difficulty were applied by adjusting the velocity rate at which the instructions were provided to the subject according to his/her maximal capacities measured beforehand. A condition without any concomitant cognitive task was added to constitute a baseline behavior. Two basic components, the horizontal center-of-gravity movements and the horizontal difference between center-of-gravity and center-of-pressures were computed from the complex center-of-pressure recorded movements. It was hypothesized that increasing the delay should infer less interaction between postural control and task solution. The results indicate that both mental-calculation and mental-navigation tasks induce reduced amplitudes for the center-of-pressure minus center-of-gravity movements, only along the mediolateral axis, whereas center-of-gravity movements were not affected, suggesting that different circuits are involved in the central nervous system to control these two movements. Moreover, increasing the delays task does not infer any effect for both movements. Since center-of-pressure minus center-of-gravity expresses the horizontal acceleration communicated to the center-of-gravity, one may assume that the control of the latter should be facilitated in dual-tasks conditions, inferring reduced center-of-gravity movements, which is not seen in our results. This lack of effect should be thus interpreted as a modification in the control of these center-of-gravity movements. Taken together, these results emphasized how undisturbed upright stance control can be impacted by mental tasks requiring attention, whatever their nature (calculation or navigation) and their relative difficulty. Depending on the provided instructions, i.e. focusing our attention on body movements or on the opposite diverting this attention toward other objectives, the evaluation of upright stance control capacities might be drastically altered.

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1. Introduction

Postural control is a complex sensorimotor task requiring the participation of various structures of the central nervous system including the spinal cord, the brain stem, the cerebellum, and the cortex (Maki & McIlroy, 2007). Even though standing can be easily and automatically achieved without particular attention (one can, for instance, stand for long periods and speak in parallel), one can also be required to focus on his/her balance as a task when participating in a scientific experiment.

The effects of change in attention on postural control have been investigated for three decades using dual-task protocols. Compared to a single task, in which subjects are required to only focus on their postural stability, performing a cognitive task has noticeable effects on postural stability since decreased or increased postural movements have been reported (see Woollacott and Shumway-Cook (2002) and Lacour, Bernard-Demanze, and Dumitrescu (2008) for review). Several factors, relative to the specificity of the task and the way postural control is analyzed, are thought to be responsible for these contrasted results. If various studies documented the effect of the nature of the cognitive task (Fraizer & Mitra, 2008; Hwang, Lee, Chang, & Park, 2013; Lacour et al., 2008; Woollacott & Shumway-Cook, 2002), only a few studies aimed to question the way postural control was analyzed, and notably the mechanisms underlying the CP displacements. The CP is a complex variable since it comprises both the vertically projected displacements of CG_v and its difference ($CP-CG_v$). Both variables do not have the same meaning as CG_v is often used to assess the postural performance and therefore the efficiency of postural control while $CP-CG_v$ is a fair index of the neuro-muscular means called into play for achieving the postural control (Rougier, 2008). This last point can be easily emphasized by using forwardly leaning postures which solicit in larger proportion the calf muscles (Rougier, Burdet, Farenc, & Berger, 2001). In that case, only the amplitudes of the $CP-CG_v$ movements increase whereas those of the CG_v remain unchanged. In addition, by being proportional to the horizontal acceleration communicated to the CG (Brenière, Do, & Bouisset, 1987), the $CP-CG_v$ amplitudes make more or less complex the CG control. As a result, a decrease of the $CP-CG_v$ movements should be viewed as facilitating the control of the CG_v and therefore of the whole posture whereas its increase should worsen the CG_v control. Using this partitioning, Vuillerme and Nafati (2007) have highlighted that focusing on postural control impacted more the $CP-CG_v$ movements than the CG_v movements, thus confirming the EMG decrease in dual-tasks observed in older peoples by Simoneau, Billot, Martin, Perennou, and van Hoecke (2008). Later, the same authors (Nafati & Vuillerme, 2011) reported concomitant decreases of $CP-CG_v$ and CG_v movements during a short-term digit-span memory task. Thus, whereas a $CP-CG_v$ decrease might be a characteristic feature of double tasks protocols, the contrasted results with CG_v movements remains not fully understood.

In our mind, we may better understand these contrasted results from a motor control point of view. Indeed, more or less CP displacements need not necessarily equate to more or less control but may be the result of a defined strategy (Riley, Wong, Mitra, & Turvey, 1997). One way to differentiate the two explanations (less control vs other kind of control) is to use the fractional Brownian motion (fBm) modeling (or stabilogram-diffusion analysis). In this modeling, the displacements (CP, CG_v or $CP-CG_v$) can be considered as the result of a combination of deterministic and stochastic (random walk) processes whose nature is determined from the degree of correlation between past and future increments. Interestingly, the computing of scaling regimes enables a quantification of these controls which, by analogy, may account for feedback (corrective) or feedforward (exploratory) control mechanisms (Collins & de Luca, 1993; Riley et al., 1997). We have also shown that the $CP-CG_v$ and CG_v movements were largely controlled over the shortest (exploratory) and longest times intervals (correction), respectively (Rougier & Caron, 2000). This two-parts strategy may reflect in fact two successive and alternative objectives for the postural control system to control standing still: exploratory (feedforward) movements over the short term (obtaining information about the postural system) and "performatory" (feedback) over the long term (using this information) (Riley et al., 1997).

In dual-tasks protocols, the nature and the difficulty of the task likely explains the reported differences. These topics have been poorly investigated. On one hand, different natures of the task (e.g., calculation vs. navigation) are thought to activate different parts of the cerebral areas. Brain imaging techniques indicate that the anterior part of the parieto-occipital sulcus is activated for spatial navigation task (Ino et al., 2002; Moffat, Elkins, & Resnick, 2006), whereas the intraparietal sulcus, a central amodal representation of quantity (Dehaene, Molko, Cohen, & Wilson, 2004) and the precentral and inferior prefrontal cortices are activated for calculation tasks. It is noteworthy that navigation tasks and upright stance maintenance share similar cerebral areas (Ouchi, Okada, Yoshikawa, Nobezawa, & Futatsubashi, 1999). One could therefore expect more or less interferences when associating such cognitive tasks with postural control. On the other hand, concerning the cognitive task difficulty, Pellecchia's study (2003) showed an inverse relation with resultant center-of-pressure (CP) lengths: in other words, the greater the difficulty, the larger the CP displacements. In contrast, Riley, Baker, and Schmit (2003) reported a reverse phenomenon for CP standard-deviation which decreased with task difficulty, especially along the medio-lateral (ML) axis.

To improve our knowledge on the interference between attention and postural control, we used a dual-task protocol based on two cognitive tasks, mental-calculation (MC) or mental-navigation (MN), aimed at activating various cerebral areas directly or not involved in postural control. The aim of this study was therefore twofold: 1) assessing whether mobilizing different brain structures could lead to differences in the two elementary $CP-CG_v$ and CG_v movements; 2) analyzing the form of the interaction between the cognitive tasks and postural control by modulating the time duration involved in solving the secondary cognitive tasks. Since the number of instructions constituting a cognitive task was held constant for all subjects or difficulties, inducing posturographic recordings of various durations, it was mandatory to retain parameters insensitive to