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Full Length Article

Examination of reactive motor responses to Achilles tendon vibrations during an inhibitory stepping reaction time task

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ABSTRACT

Inhibition is known to influence balance, step initiation and gait control. A specific subcomponent of inhibition, the perceptual inhibition process, has been suggested to be specifically involved in the integration of proprioceptive information that is necessary for efficient postural responses. This study aimed to investigate the inhibition requirements of planning and executing a choice step initiation task in young adults following experimental perturbation of proprioceptive information using Achilles tendon vibrations. We developed an inhibitory stepping reaction time task in which participants had to step in response to visual arrows that manipulated specific perceptual or motor inhibition according to two proprioceptive configurations: without or with application of vibrations. Performance of twenty-eight participants (mean age 21 years) showed that Achilles tendon vibrations induced an increase in attentional demands (higher reaction time and longer motor responses). Further, this increase in attentional demands did not affect specifically the different inhibitory processes tested in this reactive stepping task. It suggests that attentional demands associated with the vibratory perturbation to postural control do not lead to a shift from automatic to more attentional inhibition processes, at least in young adults.

1. Introduction

A key component of executive functions is behavioural inhibition control, which is the inhibitory ability to override an automatic, prepotent or unwanted response. This active suppression process that keeps irrelevant information from disrupting cognitive processing in general (e.g. Harnishfeger, 1995) is one of the most critically discussed concepts in psychology (Miyake et al., 2000; Nigg, 2000; Van der Molen, 2000). The results from a variety of experimental tasks enable a conceptualization of inhibition in terms of a range of processes that vary as a function of automatic vs. attentional control requirements (Nigg, 2000) or specific inhibitory demands (Dempster & Corkill, 1999). Within this challenging conceptual context, mobility (step initiation, gait) and upright standing associated with different aspects of inhibition have been examined using conflict resolution tasks, mainly in dual-task designs. Overall, requirements in inhibitory processing have been shown to interfere with balance, step initiation and gait control in both young and older adults (Dault, Geurts, Mulder, & Duysens, 2001; Lord & Fitzpatrick, 2001; Melzer & Oddsson, 2004; Potocanac, Smulders, Pijnappels, Verschueren, & Duysens, 2015; Potocanac et al., 2014; Redfern, Jennings, Mendelson, & Nebes, 2009; Sparto et al., 2013, 2014). In this vein, we aimed to explore the degree to which specific and distinct inhibition control processes (Magnard, Berrut, Cornu, & Deschamps, 2017; Nassauer & Halperin, 2003) might influence the automatic and controlled processing involved in

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reactive postural responses of young adults.

It is well known that effective automatic control of posture while standing involves the collection and processing of sensory cues stemming from visual, vestibular and proprioceptive systems (Horak & Macpherson, 1996). This sensory information allows the central nervous system to determine the position and orientation of body segments with respect to both each other and the external environment. In a step initiation task, awareness of the stance limb position and body orientation is obtained as proprioceptive feedback, in part, from the primary endings of ankle muscle spindles (Sorensen, Hollands, & Patla, 2002). A perturbed proprioceptive cue leads to an increase in the attentional demands to meet an efficient postural control (Haggerty, Jiang, Galecki, & Sienko, 2012). Nevertheless, the possibility for inhibition processes to influence postural response, as a function of automatic (lower level) or controlled (higher level) processing of proprioception, has not yet been fully addressed in a stepping reaction time (RT) task.

Interestingly, Redfern et al. (2009) investigated the relationship between the inhibition capacities and balance performance in response to different sensory conditions in a computerized motor conflict task adapted from Nassauer and Halperin (2003). Based on the original Simon task (Simon, 1969), this task included both stimulus conflict and motor response conflict, particularly in incongruent trials, allowing the distinction between the *so-called* perceptual and motor inhibition (see Germain & Collette, 2008; Magnard et al., 2017, for similar conclusions). In this framework, no correlation was found in young participants between inhibition performance and postural sway instability under any sensory conflict (e.g. standing on a sway-referenced floor making proprioceptive information unreliable). In contrast, the perceptual inhibition was associated with postural sway in older participants, emphasizing that the perceptual inhibition process may play a central role of maintaining attention to a nonsalient dimension (Redfern et al., 2009). Thus we anticipate that these inhibition processes may be more involved in young adults to cope with a more controlled (cognitive) and less automatic processing of posture such as during alterations in the proprioceptive system. This assumption is fully in line with age-related differences in the ability to focus on task-relevant inputs while ignoring or filtering irrelevant inputs (e.g. Plude, Enns, & Brodeur, 1994) and in the allocation of attentional resources for balance control (Boisgontier et al., 2013). In addition, the exploration of these inhibitory processes with the procedure of Nassauer and Halperin (2003) should allow finding specific significant impairment in one of two inhibitory processes with attentional balance control.

Based on the aforementioned investigations, we aimed to evaluate the effects of a proprioceptive perturbation on inhibitory stepping reaction time task performance in young healthy adults. More precisely, we focused specifically on the inhibition requirements of both planning and executing a choice step initiation when the availability of proprioceptive information was experimentally handled by bilateral vibrations applied to the Achilles tendons. The Achilles tendon vibrations are known to make proprioceptive information from the ankles unreliable due to the stimulation of the Ia afferent fibres that are connected to the primary spindle endings, which are interpreted by the central nervous system as a stretching of the vibrated muscle (Roll & Vedel, 1982; Roll, Vedel, & Ribot, 1989). Achilles tendon vibrations provoke a backward whole-body tilt (i.e., a backward shift of the centre of pressure [COP]; e.g., Barbieri, Gissot, Nougier, & Pérennou, 2013; Capicikova, Rocchi, Hlavacka, Chiari, & Cappello, 2006; Thompson, Bélanger, & Fung, 2007) due to the illusion of lengthening the gastrocnemius muscle through a reflex contraction (Eklund, 1972; Roll et al., 1989). By manipulating the experimentally altered proprioceptive information through bilateral Achilles tendon vibrations, we hypothesized that this vibratory perturbation during the inhibitory stepping reaction time task would induce higher attentional demands, thereby resulting in poorer performances of both reaction time and motor response. In addition, specific attention was established on a potentially specific impact of Achilles tendon vibrations on inhibitory stepping reaction time performance while addressing the specific stimulus conflict (perceptual inhibition) and the response conflict (motor inhibition).

2. Methods

2.1. Participants

Twenty-eight young healthy adults (mean age 21 ± 1.8 years, range 18–25 years; height 174.1 ± 9.5 cm; weight 69.3 ± 11.1 kg; 10 females) volunteered to participate in this study. None had a history of vestibular or neurological disorders, according to self-report data. The experiment was performed with the written informed consent of each participant and was conducted in accordance with the Helsinki Statement (1964).

2.2. Cognitive tasks

Inhibitory function was evaluated using a cognitive test paradigm adapted from Nassauer and Halperin (2003) that had been used in other studies (e.g. Bedard, Trampush, Newcorn, & Halperin, 2010; Germain & Collette, 2008; Jennings, Mendelson, Redfern, & Nebes, 2011; Mendelson, Redfern, Nebes, & Jennings, 2010; Redfern et al., 2009; Schulz et al., 2005; Sparto et al., 2013). It was composed of different subtests that assessed two separable types of inhibitory control processes: perceptual and motor inhibition. These subtests were designed to measure the RT to stimulus conflict resolution or response conflict resolution using PsyScope software (Cohen, MacWhinney, Flatt, & Provost, 1993).

Precisely, the participants were asked to respond to a 3.8 cm long black arrow that was displayed on a 46 cm diagonal cathode ray tube monitor and pointed to either the right or left (Figs. 1and 2A) or in an up or down direction (Figs. 1 and 2B), depending on the step direction (lateral *versus* anteroposterior). A typical trial started with the presentation of a black central fixation cross for 300 ms, followed by the arrow, which was presented for 500 ms. The interval between the warning signal (the cross) and the response signal (the arrow) was preset and varied randomly between 1 s and 2 s so that the participant could not anticipate the stimulus onset (Mendelson et al., 2010). Participants were allotted a maximum of 2 s to respond and were given no feedback about their