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VISION AND PROPRIOCEPTION DO NOT INFLUENCE THE EXCITABILITY OF THE CORTICOMOTONEURONAL PATHWAY DURING UPRIGHT STANDING IN YOUNG AND ELDERLY ADULTS

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Abstract—This study investigated the influence of vision and proprioception on the excitability of direct corticospinal (corticomotoneuronal) pathway to the soleus in young and elderly adults during upright standing. Ten young and 10 elderly adults stood upright on a rigid surface with eyes open or closed, and on foam mat with eyes open. The corticomotoneuronal excitability was investigated by assessing facilitation of the soleus H-reflex induced by subthreshold transcranial magnetic stimulation (TMS). The torque produced by the plantar flexor muscles during a maximal voluntary contraction was also measured. The maximal plantar flexion torque was significantly lower in elderly than in young adults ($p < 0.05$). The activity of leg muscles, recorded by electromyography (EMG) was greater in elderly than in young adults regardless of balance conditions ($p < 0.05$), and greater when standing on foam than in the other conditions ($p < 0.05$), regardless of age. The H-reflex facilitation was greater for elderly [182.9 (45)%] than young adults [130.5 (33.1)%; $p < 0.05$] but did not differ across sensory conditions ($p > 0.05$). However, the amplitude of the H reflex conditioned by TMS relative to the amplitude of the test H reflex ratio was positively associated with EMG activity of the plantar flexor muscles during upright standing ($r^2 = 0.47$; $p < 0.001$). These results indicate that regardless of age the excitability of the corticomotoneuronal pathway is not modulated with changes in the sensory conditions during upright standing. Nonetheless, the corticomotoneural drive to control leg muscle during upright standing increases with the level of soleus muscle activity.

Key words: aging, balance, MEP, TMS, upright standing, corticospinal excitability.

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Abbreviations: aEMG, Average value of the rectified EMG; CoP, center of pressure; EMG, electromyography; FEO, Foam Eyes Open condition; MEP, motor evoked potential; MVC, maximal voluntary isometric contraction; REC, Rigid Eyes Closed condition; REO, Rigid Eyes Open condition; TMS, transcranial magnetic stimulation.

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INTRODUCTION

From a biomechanical point of view, human standing is classically considered as an inverted pendulum with gravity causing forward toppling about the ankle joint, which is prevented by calf muscle activity (Loram et al., 2005). The ability to maintain upright standing is therefore determined by the force produced by the plantar flexor muscles that results from the activation signal consisting of descending and peripheral inputs converging onto the motor neuron pools of the involved muscles. Previous work showed that during normal upright standing, the group I afferent inputs onto spinal motor neurons, as assessed by the Hoffmann (H) reflex, was depressed and the amplitude of the motor evoked potential (MEP) from transcranial magnetic stimulation (TMS) was enhanced when compared with seated or supported upright position (Tokuno et al., 2009). Furthermore, these adjustments appear to be more pronounced in elderly than in young adults (Baudry et al., 2014). Nonetheless, the activation signal sent to the motor neuron pool is shaped according to proprioceptive, visual, and vestibular inputs (Fitzpatrick et al., 1992) that vary with balance conditions (Peterka, 2002). For example, the inputs from soleus muscle spindle (Ia) afferents onto homonymous motor neurons is depressed at a presynaptic level when vision is suppressed and when standing on an unstable surface (foam mat) in both young and elderly adults (Baudry and Duchateau, 2012). Such a modulation is consistent with a shift toward greater cortical contribution in the postural control of challenging balance conditions (McIlroy et al., 2003).

One limitation to investigate changes in corticospinal excitability during upright standing, especially in unstable conditions for elderly adults, is related to possible large balance perturbations elicited in response to TMS. Furthermore, an increase in MEP amplitude may reflect changes in the excitability of cortical motor neurons and spinal interneurons (Petersen et al., 2003) that comprise the corticospinal pathway, limiting the ability to address the question of the locus of the modulation in the corticospinal pathway. The monosynaptic projection of cortical motor neurons (corticomotoneuronal pathway) to spinal motor neurons, however, can be assessed by a spatial facilitation method based on conditioning Ia afferent inputs onto spinal motor neurons (H reflex) by subthreshold TMS

(Nielsen et al., 1993; Petersen et al., 2003). By setting the TMS intensity below motor threshold, the risk of large postural perturbations is drastically reduced. Such an approach has indicated that corticomotoneuronal projections contribute to postural control during perturbed upright standing (Taube et al., 2006). A greater excitability of the corticomotoneuronal pathway to the soleus during upright standing has been also suggested in elderly compared with young adults (Baudry et al., 2014), but the influence of sensory conditions on corticomotoneuronal excitability during upright standing remains unknown.

The aim of this study, therefore, was to assess the excitability of the corticomotoneuronal pathway to the soleus in young and elderly adults. The soleus muscle has been targeted to supplement previous work on upright standing (Lavoie et al., 1995; Goulart et al., 2000; Soto et al., 2006; Taube et al., 2006; Tokuno et al., 2009; Baudry and Duchateau, 2012; Baudry et al., 2014) that has mainly focused on this muscle as it represents the main active leg muscle during unperturbed upright standing. Based on the greater increase in soleus Ia presynaptic inhibition between upright standing with modified visual (eyes closed) and proprioceptive (foam surface) conditions (Baudry and Duchateau, 2012) in elderly adults, it was hypothesized that corticomotoneuronal excitability would increase with changes in visual or proprioceptive conditions, but more so in elderly adults.

EXPERIMENTAL PROCEDURES

Subjects

Ten young adults (23–37 yrs; five women) and 10 elderly adults (62–80 yrs; eight women) volunteered to participate in the study after written informed consent was obtained. None of the participants was institutionalized, depressed (Geriatric Depression Scale < 10), at risk for dementia (Montreal Cognitive Assessment > 26), taking medications that could influence balance (sedatives, hypnotics, antidepressants and benzodiazepines; Woolcott et al., 2009), or reported any neurological issue. All participants reported to the laboratory for a single session (2–3-h duration), and were asked to refrain from intense exercise for 24 h before testing. Approval for the project was obtained from the local Ethics Committee, and all procedures used in this study conformed to the Declaration of Helsinki.

Force platform

Subjects were required to stand on a force platform (OR6-6-2000, Advanced Mechanical Technology, Watertown, MA, USA) to record the ground reaction forces allowing to compute the displacement of the center of pressure (CoP). The signals from the force platform were sampled at 100 Hz, A/D converted (Power 1401, 16-bit resolution, Cambridge Electronic Design, UK) and stored on a computer. Subjects stood with the arms at their sides and were instructed to refrain from performing any head or limb movements; this was aided by having them fixate a target positioned at eye level 1.5 m in front of them. Three balance conditions were assessed consisting of standing upright on a rigid surface (wooden support of similar dimensions that the foam mat, see below) placed over the force platform with their eyes either open (Rigid Eyes Open condition: REO) or closed (Rigid Eyes Closed condition: REC), and on a foam mat [Balance-pad Airex (50 × 41 × 6 cm); Sins, Switzerland] with their eyes open (Foam Eyes Open condition: FEO). The rigid surface placed over the force platform was used to provide similar upward shift in the subject center of mass compared with the foam mat, and the calculation of the CoP location was corrected to accommodate the influence of the surface thickness (wood or foam) relative to the coordinate frame for the horizontal forces (Baudry and Duchateau, 2012). Subjects self-selected an initial foot position that was kept constant throughout the experiment by tracing foot position on the rigid surface and the foam mat.

EMG recordings

The surface electromyogram (EMG) signals were recorded from the soleus, gastrocnemii medialis and lateralis, and tibialis anterior of the right leg with surface electrodes (silver–silver chloride electrodes 8-mm diameter) placed in a bipolar configuration with an inter-electrode (center to center) distance of 2 cm. Before attaching the electrodes, the skin was shaved when necessary and cleaned with a solution of alcohol, ether, and acetone to reduce the impedance at the skin–electrode interface. The electrodes were filled with gel and attached longitudinally over each muscle belly with an adhesive tape. The electrodes for the soleus were placed 3 cm below the muscle–tendon junction of the gastrocnemius medialis in line with the Achilles tendon. The electrodes for gastrocnemii medialis and lateralis were placed midway between femoral condyles and the respective muscle–tendon junction. The electrodes for tibialis anterior were placed at one third of the distance between the fibular head and the lateral malleolus, and 1 cm lateral to the tibia. The reference electrodes were placed over the tibia. The EMG signals were amplified (1000×) and band-pass filtered (10–1000 Hz) prior to A/D sampling at 2 kHz (Power 1401, 16-bit resolution, Cambridge Electronic Design, UK) and storage on a computer.

Electrical stimulation

Electrical stimuli (1-ms duration) applied to the tibial nerve were delivered via a constant current stimulator (DS7A, Digitimer, Hertfordshare, UK), that was connected to surface electrodes (silver–silver chloride electrodes 8-mm diameter) attached with an adhesive tape to the skin at the knee level of the right leg. The cathode was placed in the popliteal fossa and the anode located just above the patella (Schieppati, 1987). The optimal site of stimulation was determined during upright standing by moving an electrode pen (cathode) until the site to elicit