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Effects of short-term training combining strength and balance exercises on maximal strength and upright standing steadiness in elderly adults

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ABSTRACT

This study investigated the effects of two training programmes of 6 weeks combining strength and balance exercises in different proportions. One training programme [$n = 10$; 71.4 (6.3) years] consisted mainly of strength exercises (ST) and the other programme [$n = 8$; 71.4 (6.4) years] included a majority of balance exercises (BT). Maximal strength of lower leg muscles and centre of pressure (CoP) steadiness during upright stance in various sensory conditions were measured before and after training. The input–output relation of motor evoked potential (MEP) induced by transcranial magnetic stimulation and H reflex was also assessed in soleus during upright standing. The maximal strength of the ankle plantar flexor muscles increased after training programmes ($p < 0.001$) with a trend for greater gain in ST (+35.7%) compared with BT (+20.8%, $p = 0.055$). The gain in strength was positively correlated with the increase in voluntary activation ($p < 0.001$). Both training programmes decreased maximal amplitude and mean fluctuations of CoP displacements recorded in the backward–forward direction when standing on a foam mat ($p < 0.05$) but not on a rigid surface. The electromyographic activity of the ankle plantar flexor muscles during upright standing decreased ($p < 0.05$) after training but not for the tibialis anterior. Results obtained for H reflex and MEP input–output relations suggest an increased efficacy of Ia afferents to activate low-threshold motor neurones and a decrease in corticospinal excitability after training. This study indicates that short-term training combining strength and balance exercises increases maximal strength and induces change in the neural control of lower leg muscles during upright standing.

1. Introduction

Ageing is associated with reduced maximal strength (Baudry et al., 2005; Vandervoort and McComas, 1986) and impaired balance (Baudry and Duchateau, 2012; Billot et al., 2010), measured as an increased magnitude of the fluctuations of the centre of pressure (CoP steadiness). CoP steadiness reflects the ability of an individual to maintain the vertical projection of the centre of mass within the base of support with minimal postural sway (Shumway-Cook et al., 1988). The decrease in CoP steadiness likely reflects alterations in the control of upright standing that should place elderly adults at a higher risk of falls (Horak et al., 1989). Even though a decrease in maximal strength predisposes elderly adults to functional limitations (Clark and Manini, 2012) and contributes to alter CoP steadiness (Billot et al., 2010; Orr, 2010), there is little evidence for a positive effect of strength training on CoP steadiness (Howe et al., 2011; Orr et al., 2008). In contrast, training programmes consisting of exercises challenging postural balance improve balance control but not muscle strength (Howe et al., 2011; Wolfson et al., 1996). Because of these specific adaptations, it was suggested that a combined strength and balance exercise programme (Brouwer et al., 2003; Granacher et al., 2011) would improve motor function and postural stability, a requisite for limiting the age-related increase in the risk of falls (Horak et al., 1989). In that context, a relevant parameter to address is the influence of the respective amount of balance and strength exercises to include in the training programme. Indeed, the extent of strength gain in response to strength training depends on the number of sets composing the training programme (Borst et al., 2001; Hansen et al., 2012; Kraemer et al., 2000) and, similarly, the amount of balance exercise determines in part the extent of the improvement in CoP steadiness (Howe et al., 2011).

During upright standing, recent work suggests a decreased efficacy of Ia afferents to activate spinal motor neurones accompanied by an increased corticospinal excitability during upright standing in elderly compared with young adults (Baudry et al., 2014a; Papegaaij et al., 2014b). These changes may reflect adaptations in response to the age-related alterations within the nervous and muscular systems (Papegaaij et al., 2014a), such as the decrease in muscle mass, number of motor units (Vandervoort, 2002), loss of distal large myelinated sensory axons, and altered anatomical and physiological characteristics of

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Abbreviations: CoP, centre of pressure; MEP, motor evoked potential; TMS, transcranial magnetic stimulation; REO, rigid, eyes open condition; REC, rigid, eyes closed; FEO, foam, eyes open condition; aEMG, average value of the rectified electromyogramme; MVC, maximal voluntary contraction; CAR, central activation ratio.

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muscle spindles (Shaffer and Harrison, 2007). In young adults, balance training decreased corticospinal excitability in tibialis anterior during various balance tasks (Beck et al., 2007; Schubert et al., 2008) whereas no significant change in H-reflex amplitude, that assesses the synaptic efficacy of Ia afferents to discharge motor neurones, was reported after similar training (Taube et al., 2007). Such data, however, are not available in elderly adults, especially regarding combined training. Accordingly, it is of particular interest to investigate whether this type of training programme may influence neural adjustments during upright standing in elderly adults.

The current study, therefore, had a double objective: 1) to investigate the changes in maximal strength and CoP steadiness following two training programmes including both strength and balance exercises but in different proportions: one training programme (ST) mainly consisted of strength exercises and the other programme (BT) included mainly balance exercises; and 2) to study whether corticospinal excitability and synaptic efficacy of Ia afferents to discharge motor neurones change after the training programmes when assessed during upright standing. We expected the gain in strength to be greater in elderly adults enrolled in the ST programme, but greater improvement in CoP steadiness for those participating in the BT programme. Furthermore, based on the increased MEP and decreased H reflex during upright standing in elderly compared with young adults (Baudry et al., 2014a), likely related to age-related changes in maximal strength (Baudry et al., 2014b) and proprioceptive system (Goble et al., 2011), we hypothesize that both training programmes can reverse these changes in different proportions.

2. Methods

2.1. Subjects

Twenty two subjects aged over 60 years volunteered to participate in this study. All subjects signed an informed consent and underwent a medical examination prior to their participation in the study. Approval for the project was obtained from the local Ethics Committee, and all procedures used in this study conformed to the Declaration of Helsinki.

Individuals with Parkinson's disease, multiple sclerosis, diabetes, stroke or cardiac incidents were excluded from this study. Volunteers who had orthopaedic problems within 12 months prior to the study were not enrolled. Participants were not institutionalized, neurologically damaged, depressed (Geriatric Depression Scale < 10), at risk for dementia (Montreal Cognitive Assessment > 26) or taking medications that could influence balance (sedatives, hypnotics, antidepressants and benzodiazepines; Woolcott et al., 2009).

The twenty subjects were randomly assigned either to ST (10 subjects) or BT (10 subjects). Due to injury unrelated to training, two subjects in BT had to stop their participation. A total of 18 subjects completed the 6-week training (93% compliance to training sessions), with the ST group composed of 10 subjects [2 men, age: 71.4 (6.3) years, height: 163.5 (6.4) cm, weight: 60.3 (10.2); mean (SD)] and the BT group composed of 8 subjects [2 men, age: 71.4 (6.4) years, height: 166.0 (5.5) cm, weight: 67.6 (13.7) kg]. Each subject participated in at least one familiarization session and two experimental sessions lasting 2–3 h (one before and one after the 6-week training programme). During the familiarization session, subjects practiced the different tasks used during the experimental sessions. Among the 18 subjects that have completed the training, six had participated in an additional experimental session performed six weeks before the start of the training programme, to serve as a control group. During this period, no training was carried out and the subjects maintained their normal daily activities. Two additional subjects, who did not perform the training thereafter, were incorporated in the control group that was therefore composed of 8 subjects [2 men, age: 70.1 (5.9) years, height: 165.2 (5.9) cm, weight: 65.9 (12.6) kg].

2.2. Experimental protocol

2.2.1. Force platform

Subjects were requested to stand on a force platform (OR6-6-2000, Advanced Mechanical Technology, Watertown, MA, USA) to record the ground reaction forces allowing to track the CoP position. 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 in a bipodal position with a 10-cm distance between feet (heel to heel) and the forefoot oriented laterally with a 30-degree angle between feet (each foot was rotated 15° from the forward direction). Subjects stood with the arms at their sides and were instructed to refrain from performing any head or limb movements; this was aided by asking them to fix 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) 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 ($50 \times 41 \times 6$ cm); Sins, Switzerland] with their eyes open (foam, eyes open condition: FEO) (Baudry and Duchateau, 2012; Baudry et al., 2014b).

2.2.2. Surface electromyogramme

The surface electromyogramme (EMG) signals were recorded from soleus, gastrocnemius medialis and tibialis anterior of the right leg with surface electrodes (silver–silver chloride electrodes of 8-mm diameter) placed in a bipolar configuration with an inter-electrode (centre to centre) 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 adhesive tape. The electrodes for soleus were placed 3 cm below the muscle–tendon junction of the gastrocnemius medialis in line with the Achilles tendon. The electrodes for gastrocnemius medialis were placed midway between the femoral condyle and the 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. Particular attention was drawn to place the electrodes at the same locations across experimental sessions by taking anatomical landmarks. 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.

2.2.3. Electrical nerve stimulation and transcranial magnetic stimulation

Electrical stimuli (1-ms duration) applied to the tibial nerve were delivered via a constant current stimulator (DS7A, Digitimer, Hertfordshire, UK), that was connected to two surface electrodes (silver–silver chloride electrodes of 8-mm diameter) attached to the skin with adhesive tape 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 a pen electrode (cathode) until the site to elicit an H reflex in soleus with the largest amplitude at a given intensity was identified. The input–output relations for H reflex and M wave were determined in REO by progressively increasing the stimulus intensity in steps of 1 mA (5 stimulations by step) until the M-wave amplitude reached a plateau (M_{max}; Schieppati, 1987).

Transcranial magnetic stimulation (TMS) was applied over the left motor cortex by a double-cone coil (Magstim 200 stimulator, Magstim, Dyfed, UK). The optimal site of stimulation was determined by moving the coil until the site eliciting a motor evoked potential (MEP) in soleus with the largest amplitude at a given intensity was identified. A custom-made helmet was used to maintain the position of the coil without