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The involvement of ankle muscles in maintaining balance in the upright posture is higher in elderly fallers

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ABSTRACT

The purpose of this study was to determine whether the mechanical contribution of ankle muscles in the upright stance differed among young adults (YA) (n = 10, age: ~24.3), elderly non-fallers (ENF) (n = 12, age: ~77.3) and elderly fallers (EF) (n = 20, age: ~80.7). Torque and electromyographic (EMG) activity were recorded on the triceps surae and tibialis anterior during maximum and submaximum contractions in the seated position. EMG activity was also recorded in subjects standing still. Plantar flexor (PF) and dorsal flexor (DF) torques generated in the upright posture were estimated from the torque–EMG relationship obtained during submaximum contractions in the seated position. Center of pressure (CoP) displacement was measured to quantify postural stability. Results showed that, in upright standing, EF generated greater ankle muscle relative torque (i.e. PF + DF torque in the upright stance/PF + DF during maximum isometric torque) than non-fallers (i.e. ENF, YA). The greater involvement of ankle muscles in EF was associated with higher CoP displacement. PF + DF torque in the upright stance was no different among the groups, but PF + DF torque during maximum effort was impaired in older groups compared with YA and was lower in EF than ENF. These results suggest that the postural stability impairment observed with aging is highly related to ankle muscle weakness.

1. Introduction

Falls are a leading cause of morbidity and mortality in older people and concern approximately 30% of the population aged ≥65 years (Campbell et al., 1989; Rubenstein and Josephson, 2002). Several authors have reported that the deterioration in postural stability is a key factor in falls. Indeed, it is common to observe that postural sway during the quiet stance is larger in older adults than in younger individuals and even more pronounced in elderly adults with recent history of falls (Cattagni et al., 2014; Fernie et al., 1982; Maki et al., 1994; Mignardot et al., 2014; Simoneau et al., 2008). In an earlier investigation, we found that the center of pressure (CoP) displacement in fallers and non-fallers correlated negatively with the maximum isometric torque (MIT) of ankle muscles (Cattagni et al., 2014). Moreover, we observed that EF were weaker and that the slope of the regression line for EF was steeper than that for non-fallers implying that below a certain level of muscle force the functional impact of the decline in ankle muscle strength is greater. This result suggests that muscular weakness is a major cause of postural instability and may increase the risk of falling. Considering the inverted pendulum model, which is generally used to describe the upright stance in humans, the equilibrium equation for the foot shows that a variation in muscle torque developed at the ankle joint is directly and proportionally translated into a variation in CoP position (Morasso and Schieppati, 1999). This was confirmed by authors who reported that increased CoP displacement was related to increased calf muscle electromyographic (EMG) activity (Amiridis et al., 2003; Billot et al., 2010; Loram et al., 2004). In 2010, Billot et al. found a strong correlation between ankle muscle torque generated in the upright posture (expressed as a percentage of the torque developed during maximum voluntary contraction) and CoP displacement in young and elderly adults (Billot et al., 2010). They also reported that this relative torque was greater in elderly non-fallers (ENF) than in young adults (YA), thus indicating that aging is associated with an increased implication of ankle muscles in maintaining balance in the upright stance. As far as we know, no investigation has measured the relative contribution of ankle muscles in the upright stance in elderly people with a history of falls.

Therefore, the first purpose of this study was to determine whether the mechanical contribution of ankle muscles in the upright stance differed among young adults, elderly non-fallers and elderly fallers. As

Abbreviations: AMIT, agonist maximum isometric torque; CoP, center of pressure; DF, dorsal flexors; EF, elderly fallers; EMG, electromyographic; ENF, elderly non-fallers; MVC, maximum voluntary contraction; MIT, maximum isometric torque; PF, plantar flexors; RMS, root mean square; YA, young adults.

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EF are weaker and more unstable (Cattagni et al., 2014), we hypothesized that the relative torque needed to maintain the upright stance would be greater in EF than in ENF.

Several authors found that the MIT of plantar flexors (PF) decreased during aging whereas the MIT of dorsal flexors (DF) seemed less sensitive to the aging process (Billot et al., 2010; Cattagni et al., 2014; Simoneau et al., 2009). This observation may be extended to EF since we recently found that PF MIT was 33% lower in EF than in ENF while DF MIT was only 24% lower in EF (Cattagni et al., 2014). Therefore, the second aim was to determine, the relative contribution of both the antagonist ankle muscle groups in maintaining postural balance for the three populations (i.e. YA, ENF and EF). We supposed that the PF relative torque required to maintain the upright posture would be greater in ENF and even more so in EF than in YA while the DF relative torque would be less influenced by aging and by the history of falling. A greater mechanical contribution of PF, especially for EF, could imply a change in the muscle activation strategy adopted to maintain the upright posture.

2. Methods

2.1. Participants

Forty-two volunteers aged between 18 and 89 years old participated in this experiment. The population included three groups according to age and the history of falls: 10 healthy YA (age: 24.3 ± 6.3 years), 12 healthy ENF (age: 77.3 ± 5.2 years) and 20 EF (age: 80.7 ± 6.4 years). For subjects aged between 60 and 90 years old, the history of falls in the previous 6 months was recorded by interview. People who had fallen unexpectedly at least once in the previous six months and without musculoskeletal impairment were included in the EF group. The YA were students at the University of Burgundy. Exclusion criteria for all subjects were myopathy, neurological disorders (cerebral vascular accident, multiple sclerosis, Parkinson's disease), serious visual impairment, body mass index (BMI) >35 and impaired cognitive status (score of less than 23 on the Mini Mental State Examination). Informed written consent was obtained from all participants after they had been fully informed of all potential risks, discomfort and benefits of the study, which was approved by the local ethics committee.

The protocol of the current investigation was approved by the French National Drugs and Health Administration and by the National Ethics Committee section Dijon Est I and was carried out in accordance with the Declaration of Helsinki.

2.2. Data recording

2.2.1. MIT

Participants were examined in the seated position, their trunk strapped to a chair and inclined backwards at 40° to the vertical in order to minimize body motion, the knee joint angle at 180° and the ankle joint angle at 90°. Torque was measured with the foot secured by two straps to the footplate of a custom-made ergometer developed by the mechanical workshop of a local engineering school (I.U.T. Génie Mécanique, Dijon, France). The center of rotation of the ergometer shaft was aligned with the anatomical ankle flexion–extension axis. The footplate was connected to a strain-gauge transducer (Société Doerler-Vandoeuvre, France) and an amplifier (PM Instrumentation, model 1300B, amplification: 8 V = 200 Nm, France). Torque was sampled at a frequency of 2 kHz and processed by a multichannel analogue-digital converter (Biopac Systems Inc., USA).

2.2.2. EMG recordings

EMG activity from the soleus, gastrocnemius medialis, gastrocnemius lateralis and tibialis anterior muscles was recorded during the postural task, and submaximum and maximum contractions. First, the subjects' skin was carefully prepared by shaving and cleaning with alcohol. Then, for soleus measurements, pairs of Ag/AgCl bipolar surface electrodes (Ambu Blue sensor M, Ambu A/S, Denmark) of 15 mm diameter with an interelectrode distance (center-to-center) of 2 cm were placed along the mid-dorsal line of the leg, approximately 5 cm below the insertion of the two heads of the gastrocnemii on the Achilles tendon (De Luca, 1997). Medial and lateral gastrocnemii recording electrodes were fixed lengthwise over the middle of the muscle belly. For the tibialis anterior, which represents the dorsal flexor group, the electrodes were positioned at 1/3 on the line between the fibula and the tip of the medial malleolus (Duclay et al., 2009; Hermens et al., 2000). The reference electrode was placed in a central position between the two gastrocnemii bellies on the right leg. The EMG signal was amplified with a bandwidth frequency ranging from 10 Hz to 5 kHz (Gain = 1000). The EMG and mechanical signals were sampled at 2 kHz with the Biopac acquisition system and stored with commercially available software (Acqknowledge, MP 150, USA) for off-line analysis.

2.2.3. Postural stability

CoP displacement during the static postural task was assessed via a force-platform (Stabilotest, TechnoConcept, Cereste, France). This platform was composed of three force sensors which instantaneously measured the coordinates of the point of application of the resultant of the ground reaction forces or CoP. Data from the force-platform were sampled at a frequency of 40 Hz and were synchronized by triggering with the Biopac acquisition system.

2.3. Experimental procedure

All measurements were made in one experimental session lasting approximately 2 h. All subjects first carried out the orthostatic postural task and then the maximum voluntary contraction (MVC) task to avoid interference due to fatigue during the postural task.

2.3.1. Postural task

During the postural task, subjects stood barefoot on the force-platform, with the two anteroposterior feet axes forming an angle of 30° (distance between the heels = 2 cm) and with their arms alongside their body. The subjects were asked to remain as still as possible, looking straight ahead at a target point located at eye height and placed at a distance of 150 cm in front of them. This postural task was repeated three times, and a rest period of 1 min was given between trials. During each 30 s trial, CoP displacement and EMG activity of soleus, gastrocnemius medialis, gastrocnemius lateralis and tibialis anterior were recorded.

2.3.2. MIT

The MIT for PF and DF was obtained during maximum voluntary isometric contraction tests performed for each leg separately. A three-minute warm-up, which included several submaximum plantar and dorsal flexions, was carried out. Subjects then performed two maximum contractions lasting 5 s at random for legs and ankle movements (i.e. Plantar flexion and dorsal flexion). A one-minute rest period was systematically given between trials to avoid any fatiguing effect on measurements. If there was a variation of more than 5% between the first and the second MVC, participants were asked to perform an additional MVC. Standardized verbal encouragement was given during attempts to produce the maximum effort. EMG activity of the soleus, gastrocnemius medialis, gastrocnemius lateralis and tibialis anterior was recorded during each MVC.

2.3.3. Submaximum contractions

To estimate PF and DF torque values during postural task for each leg, subjects were asked to perform in seated position 10–15 submaximum contractions, 4 s long, from 1% to 30% of PF and DF MIT. EMG activity of the soleus, gastrocnemius medialis, gastrocnemius lateralis and tibialis anterior was recorded during each submaximum contraction.