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Compensatory but not anticipatory adjustments are altered in older adults during lateral postural perturbations

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HIGHLIGHTS

- Anticipatory and compensatory adjustments represent the Central Nervous System's (CNSs) ability to respond to postural disturbances, preventing loss of equilibrium and falls.
- Lateral instability is a strong predictor of falls in older individuals; however, data on the modulation of these adjustments, and their relationship, in muscles that provide lateral postural stability is scarce.
- Older adults used higher compensatory activity and similar anticipatory adjustments during lateral perturbations when compared to young individuals. Nevertheless, they showed greater postural instability after the postural disturbances.

ABSTRACT

Objective: This study investigated anticipatory postural adjustments (APAs) and compensatory postural adjustments (CPAs) and their relationship in older adults during lateral postural perturbations.
Methods: Unpredictable and predictable postural disturbances were induced by a swinging pendulum that impacted at the shoulder level of two groups of older adults, non-fallers (20) and fallers (20), and in a group of young control subjects (20). The electromyographic (EMG) activity of the postural muscles and the center of pressure (COP) displacement were recorded and quantified within the time intervals typical for APAs and CPAs.
Results: Both groups of older adults (non-fallers and fallers) showed higher magnitude of EMG activity in the lateral muscles and increased COP displacement, particularly, during the CPAs time interval when compared to the young group. Older adults, however, were able to change the electrical activity of the muscles during the predictable task by generating APAs with similar magnitudes of those found in young subjects.
Conclusions: Compensatory but not anticipatory adjustments are altered in older adults during predictable lateral postural perturbations.
Significance: These findings provide new data on the role of APAs and CPAs in their relationship in older adults during external lateral perturbations and may advance current rehabilitative management strategies to improve balance control in older individuals.

1. Introduction

When postural balance is perturbed, internally (produced by the person himself) or externally (produced by outside forces), the Central Nervous System (CNS) uses two main types of postural adjustments: anticipatory postural adjustments (APAs) and compensatory postural adjustments (CPAs). The first mechanism, driven by feed-forward, is associated with the synergic activation of postural muscles and discrete body movements just before a predictable postural perturbation occurs. Their purpose is to minimize the adverse effects of the disturbance on postural balance (Nashner and McCollum, 1985; Massion, 1992; Aruin and Latash, 1995). The second mechanism, regulated by feedback, deals with the perturbation itself, and entails the coupling of postural muscle activation and movement strategies to restore postural balance after the body disturbance has occurred. This happens with predictable and unpredictable perturbations (Nashner and McCollum,

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1985; Maki et al., 2000). In the former, CPAs are preceded by APAs and the magnitude of both adjustments are relatively similar; in the later, there are no APAs, hence, the level of CPAs are comparatively higher (Santos et al., 2010a,b).

In previous studies on balance control, investigators have externally perturbed postural balance during conditions that mimic real life activities; for example, individuals standing on a moving force platform (standing inside a moving bus) (Lin and Woollacott, 2002; Amiridis et al., 2003; Hatzitaki et al., 2009) or receiving impact from a moving pendulum (colliding with another person while walking) (Aruin and Latash, 1995; Santos and Aruin, 2008, 2009; Santos et al., 2010a). In these situations, the CNS uses both APAs and CPAs in an orderly manner via different muscular synergies in accordance with the characteristics of the postural perturbation (Aruin and Latash, 1995; Santos and Aruin, 2008). For instance, when standing in the frontal plane relative to the perturbations, the lateral muscle pairs (gluteus medius and external oblique) demonstrated greater anticipatory co-activation (Santos and Aruin, 2008, 2009). These muscles have shown to be important for lateral stabilization not only when the postural balance is perturbed but also during gait initiation (MacKinnon and Winter, 1993) and lateral leg lifts (Hughey and Fung, 2005). Thus, deficits in the activity of the hip and trunk lateral muscles might influence locomotion and postural balance safety, increasing the risk of falls in certain populations, such as older adults (Hahn et al., 2005).

Age-related changes in sensory, motor and musculoskeletal systems may cause important limitations in postural stability of older adults (Lin and Woollacott, 2002; Lord and Sturnieks, 2005). Studies have shown several differences between these individuals and young adults in terms of center of pressure (COP) displacement and postural muscle activation (APAs and CPAs) either during quiet or perturbed standing (Inglin and Woollacott, 1988; Maki et al., 1999, 2000; Melzer et al., 2004). For example, older individuals have shown an increase in the activity of the postural muscles during static (Laughton et al., 2003; Billot et al., 2010) and dynamic (Hatzitaki et al., 2009; Tokuno et al., 2010) postural balance tests when compared to the young individuals. Problems with postural instability seem to be worse in older individuals with a history of falls (Bugnariu and Sveistrup, 2006; Melzer et al., 2010). For instance, they showed greater body oscillations in the anterior-posterior and medial–lateral directions, in comparison with their counterparts without a fall history, when their posture was perturbed by oscillations of a moving platform (Bugnariu and Sveistrup, 2006).

While the results of the aforementioned studies are important, data on the modulation of APAs followed by CPAs, and their relationship, as a result of lateral body instability in older individuals is scarce. In addition, it is controversial in the literature which of these control processes, APAs or CPAs, is impaired in older individuals (Bugnariu and Sveistrup, 2006; Tokuno et al., 2010); hence, CPAs preceded by APAs needed to be systematically investigated in older populations. There is evidence that lateral instability in older individuals is associated with past (Lord et al., 1999) and future risk of falls (Maki et al., 1994); as a result, hip fractures in older individuals usually involve lateral falls (Smeesters et al., 2001). A better understanding of APAs and CPAs during this condition may help improve diagnosis and treatment in balance control in older adults since postural adjustments represent the CNS's ability to respond to postural disturbances, preventing loss of equilibrium and falls.

The main purpose of this study was to investigate the strategies of postural adjustments in older individuals with and without a history of falls during lateral external postural perturbations. Both groups of older adults and a group of young individuals received predictable and unpredictable postural lateral perturbations at shoulder level induced by a swinging pendulum while the electromyographic (EMG) activity of the postural muscles and COP displacements, which quantify postural stability, were registered and later analyzed during the time windows typical for APAs and CPAs. In the present study, two main questions were addressed: (1) Are APAs or CPAs or both altered in older adults during external lateral postural perturbations? (2) Are there differences in these postural strategies between older adults with a history of falls and those who had no falls? Based on past literature, our hypotheses are that the magnitude of compensatory adjustments will be increased in both groups of older adults; however, those with a history of falls will show augmented deficits in this adjustment and more postural instability after the disturbance.

2. Methods

2.1. Subjects

A total of 60 adults were divided into three groups: 20 older non fallers, 20 older fallers, and 20 young participants. The older individuals were recruited from the Health Sciences and Sports Center (CEFID) of the Santa Catarina State University (UDESC). All older individuals practiced regular and supervised physical activity. All the participants of the young group were students and were selected from the CEFID of the UDESC. The inclusion criteria were: (1) good general health and cognition and (2) willingness to participate in the study. The exclusion criteria were: (1) any vestibular or neurological disease, (2) severe knee and hip osteoarthritis, (3) recent history of fractures and surgeries, and (4) auditory and visual impairments that could prevent the execution of the tasks. The older adults were excluded initially through screening their medical records. We included the participants who did not have reported any severe disease or dysfunction (fallers and non fallers). During the first in-person evaluation, we asked about any important dysfunction or disease, conducted the mini-mental state examination and administrated the fall history questionnaire (explained below). The 20 older fallers who participated in this study were part of a community sample of 230 physically active older adults from the CEFID-UDESC. Twenty-two percent of this sample ($n = 51$) were fallers. Their falls were associated with lower limb weakness measured during the sit to stand test (Streit et al., 2011). All participants were informed of the objectives and procedures performed in the research and signed a written informed consent approved by the local Ethics Committee (protocol number 172/10).

2.2. Materials

A questionnaire adapted by Rebelato and Morelli (2007) was used to identify the participants who had a history of falls. Falls were assessed using the following main questions: (1) Have you fallen in the last twelve months (yes/no)? (2) If yes, are you afraid of falling again (yes/no)? (3) Where did the fall occur (home/street)? (4) What was the movement you were doing at the time of the fall (anterior-posterior: walking, get-up a chair, etc.; or medial–lateral: turning or bending)? A force platform (AMTI-OR 6–7, Watertown, EUA®), positioned on the ground, was used to register the ground reaction forces and the associated moments. The EMG activity of the muscles was evaluated via electromyography (EMG System of Brazil®, model 811C, São José dos Pinhais, SP, Brazil) with an analog output, gain of 2000, band pass filter from 23 to 500 Hz, Common Mode Rejection Ratio (CMRR) greater than 80 dB, and differential amplifier. Timing of the perturbation was recorded by an accelerometer (EMG System do Brasil®, model ACL13000/03, São José dos Pinhais, SP, Brazil) attached to inferior aspect of the pendulum that was used to generate the postural perturbations. All signals were sent to a computer through a digital/analog acquisition system (model PCI 6259, National Instruments, USA) with a frequency of 1000 Hz and resolution of 16 bits,