Journal of Electromyography and Kinesiology 20 (2010) 693–700

Contents lists available at ScienceDirect

Journal of Electromyography and Kinesiology

journal homepage: www.elsevier.com/locate/jelekin

Postural reactions following forward platform perturbation in young, middle-age, and old adults

Paulo B. de Freitas [a,*], Christopher A. Knight [b], José A. Barela [a]

[a] Institute of Physical Activity and Sport Sciences, Cruzeiro do Sul University, São Paulo, SP, Brazil
[b] Department of Health, Nutrition and Exercise Sciences, University of Delaware, Newark, DE, USA

ARTICLE INFO

Article history:
Received 21 November 2008
Received in revised form 30 August 2009
Accepted 30 November 2009

Keywords:
Posture
Moving platform
Balance perturbation
EMG
Kinematics

ABSTRACT

The aim of the study was to examine how individuals of different ages react to forward balance perturbations. Thirty-six volunteers, divided into four groups [young (YA), middle-age (MA_{40} and MA_{50}), and old (OA) adults], stood on a platform that was either kept stationary, moved backward, or moved forward. EMG onset, EMG time-to-peak, iEMG, and agonist–antagonist co-activation, as well as cumulative angular excursion, maximum center of mass (CM) backward displacement, and CM time-to-reversal were assessed after forward translations. Postural synergies were assessed using principal component analysis (PCA). The results showed that OA activated their muscles later than YA [TA = 25 ms, RF = 17 ms] and OA and MA_{50} reached the peak of activation later than YA [MA_{50}:TA = 23 ms, RF = 32 ms, OA:TA = 28 ms, RF = 21 ms]. Moreover, OA kept a higher level of activation longer than all younger groups. No differences among groups were observed in co-activation, kinematic, and PCA variables. We conclude that changes in temporal EMG patterns can be seen in the fifth decade. However, such changes have no effect on the CM horizontal displacement and CM time-to-reversal after perturbation, which cannot be justified by the use of different postural synergies, suggesting that temporal aspects of muscle activation could play a minor role in controlling excessive CM displacements after perturbations.

1. Introduction

Falls are a major concern for old adults due to both physical and psychological consequences. The diminished ability to preserve body equilibrium after an unpredictable perturbation (e.g., trip and slip) could be an important contributor to the increased incidence of falls in this population. In order to reduce the risk of falls, individuals need to prevent excessive horizontal displacement of the body's center of mass (CM) and maintain the CM location within the boundaries of the base of support. To do so, the individuals must detect the direction and magnitude of the disturbance and, then, generate appropriate motor actions that are quick and forceful enough to counteract the effects of such perturbation. It is already well established that old adults show structural and functional changes in the sensory and motor systems, and that these changes decrease the ability of old adults to properly generate adequate postural adjustments to unpredictable perturbations to upright standing (Horak and MacPherson, 1996; Horak et al., 1989). However, it is still unclear if these changes could be observed before the individuals reach 60-years of age and if so, what the nature of such changes would be.

Previous studies have shown that old adults present larger CM and center of pressure (CP) horizontal displacement and require more time to reverse the direction of these displacements when compared to younger adults when exposed to unpredictable balance perturbations (Gu et al., 1996; Nakamura et al., 2001; Okada et al., 2001; Stelmach et al., 1989b). Two neuromuscular factors could play an important role in increasing CM and CP horizontal displacements and in the time to both CM and CP reversal after a perturbation: increased time (1) to activate the muscles and (2) to reach the peak of muscle activation in response to postural changes. Studies have shown that old individuals have a delayed muscle activation after a perturbation (Lin and Woollacott, 2002; Manchester et al., 1989; Nakamura et al., 2001; Okada et al., 2001; Stelmach et al., 1989a). Surprisingly, no study investigated the time needed for old adults to reach the peak level of muscle activation after a postural perturbation.

Another relevant component of an appropriate postural response is the intensity or magnitude of muscle activation. Studies have shown that old individuals activate postural muscles responsible for equilibrium recovery with lower intensities (iEMG), but maintain activation for a longer time when compared to young adults (Lin and Woollacott, 2002). Prolonged muscle activation could be considered a compensatory strategy adopted by old

* Corresponding author. Address: Instituto de Ciências da Atividade Física e Esporte – ICAFE, Universidade Cruzeiro do Sul, Rua Galvão Bueno, 868, São Paulo, SP 01506-000, Brazil.
E-mail address: deFreitasPB@gmail.com (P.B. de Freitas).

1050-6411/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jelekin.2009.11.009

individuals in order to prevent extremely large excursion of the CM. Also, as a compensatory strategy, old adults show higher indices of agonist–antagonist co-contraction than young ones (Laughton et al., 2003; Okada et al., 2001), greater joint excursions (Alexander et al., 1992), and, if the magnitude of the perturbation is excessively large, they also can alter the sequence of muscle activation from distal-to-proximal (observed in younger adults) to proximal-to-distal, and change the postural synergy from ankle to hip strategy (Manchester et al., 1989; Okada et al., 2001; Woollacott et al., 1986).

Overall, it is clear that old adults exhibit changes in their ability to respond to unpredictable balance perturbations and that they make use of compensatory strategies to prevent undue excursion of their CM after a perturbation, yet not as successfully as young adults. However, it is still unknown whether all these changes are limited to old adults or are they evident in earlier ages (i.e., middle-adulthood). Better knowledge of the time course of changes in neuromuscular and kinematic postural responses could help the development of exercise-based intervention programs designed to delay the manifestation and consequences of functional limitations. Therefore, the aim of this study was to examine age-related effects on postural responses following forward support surface translation throughout middle-adulthood and early old age. We hypothesized that aging would affect EMG and kinematic patterns of postural responses following forward platform perturbation prior to the sixth decade of life. Structural and functional changes in motor and sensory systems that occur during adulthood (Alvarez et al., 1998, 2000; Hakkinen and Hakkinen, 1991; Kido et al., 2004; Low Choy et al., 2007; Rauch et al., 2001; Vandervoort, 1992) support the idea that changes in the postural control system and, specifically, in the ability to react to an unpredictable perturbation would be already apparent even before the beginning of senescence.

2. Methods

2.1. Participants

Thirty-six healthy volunteers participated in this study. They were divided into four groups according to their ages: nine young adults between 20 and 25-years old (YA), nine middle-age adults between 40 and 45-years old (MA_{40}), nine middle-age adults between 50 and 55-years old (MA_{50}) and nine old adults (OA) between 60 and 65-years old (Gallahue and Ozmun, 2006). The average (±SE) height and body mass of each group were: YA = 1.66 (0.04) m and 60 (5) kg; MA_{40}: 1.73 (0.02) m and 72 (3) kg; MA_{50}: 1.64 (0.03) m and 70 (4) kg; OA = 1.63 (0.03) m and 77 (4) kg, respectively. These participants were recruited at the University among students and employees and from the local community, and only individuals without any apparent sensory or motor disorders and considered by themselves as sedentary (no participation in any regular physical activity program) were tested. Before being tested, participants were asked to read and, in agreeing, to sign an inform consent approved by the Research Ethical Committee, Institute of Biosciences, São Paulo State University.

2.2. Experimental apparatus and procedures

A custom movable platform (60 cm × 60 cm) was used to evaluate the participants' postural reactions to temporally unpredictable perturbations. This platform was mounted on small metal wheels positioned laterally. These wheels were placed on rails making translational movements possible. The movement of the platform was generated by a servomotor, which consisted of a controller (Compumotor – Mod. APEX 6151), a controlled stepper motor (Compumotor – Mod. N0992GR0NMSN), and an electrical cylinder (Compumotor – Mod. EC3-X3xxn-10004A-MS1-MT1M). The servomotor was controlled by custom software (Compumotor – Motion Architect for Windows). For this experiment, the platform was moved either forward or backward by 3.6 cm, during 0.4 s, with peak velocity of 15.6 cm/s and peak acceleration of 150 cm/s^2.

During the experiment, participants were instructed to stand on the platform barefoot, with feet parallel and 5 cm apart, keeping their arms vertically close to the trunk and forearms crossed over their chests. In addition, participants were asked to keep their head straight and eyes closed. Participants underwent 20 trials in which the platform was kept either stationary, moved backward or moved forward. In five randomly selected trials, the platform moved forward, in another five it moved backward, and in 10 trials it remained stationary. Each trial lasted 12 s and the perturbation was generated between the 7th and 9th second. Participants were unaware of which trials would contain perturbations. The trials without movement of the platform were used as *catch* trials to thwart any sort of anticipation by the participants. To assure each participant's safety, an experimenter was positioned at the participant's side and instructed, if necessary, to help the participant to reestablish equilibrium. In addition, participants were instructed to grasp the platform apparatus handrails or step forward or backward when their upright position was threatened. All trials requiring either assistance, a step or a grasp were performed again after the last programmed trial.

Four pairs of bipolar surface electrodes were placed on the tibialis anterior (TA), medial head of gastrocnemius (MG), rectus femoris (RF), and biceps femoris (BF) muscles of the participants' left side to record electrical activity (EMG) before and after platform translation. In addition, Optotrak (Digital Northern, Inc.) IRED emitters were placed at the apparent axis of rotation of the fifth metatarsophalangeal, ankle, knee, hip, and shoulder joints of the participants' right side as well as at the base of the moving platform. The positions of these emitters were used to calculate ankle, knee, and hip angles, as well as to indicate the beginning of platform translation. The EMG signal from each muscle was recorded at 1 kHz, amplified with a gain of 1000, band-pass filtered (20–500 Hz), converted from analog to digital by a 16 bit A/D converter, and stored for processing and analysis. Kinematic data were recorded at a sampling frequency of 100 Hz and also stored for processing and analysis.

Although the data from all 20 trials were recorded, only the forward was selected for analysis due to evidence that this perturbation was more demanding for the postural control system than the backward one. The participants explicitly reported that recovering their balance was more difficult after a forward platform perturbation when compared to the backward one. This is logical because the center of gravity (i.e., vertical projection of the CM) of a person standing upright is located more posterior with respect to the base of support (Nichols et al., 1995), and, consequently, faster and stronger postural responses are required before the CM reaches the posterior base of support boundary (Lin and Woollacott, 2002). Furthermore, a relatively small and, therefore, weaker muscle (i.e., TA compared to the triceps surae muscle group) is primarily involved in preventing the backward displacement of the CM. As observed in previous studies (Alexander et al., 1992; Prioli et al., 2006), to compare younger and old adults in less challenging postural tasks can conceal effects of aging. Therefore, we decided to avoid these potential effects by focusing our analysis only in the forward perturbation trials.

2.3. Data processing and analysis

A custom Matlab™ routine was written to process and analyze the EMG and kinematic data. In order to obtain the linear