Clinical Neurophysiology 125 (2014) 768–776

Contents lists available at ScienceDirect

Clinical Neurophysiology

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

Isolated and combined effects of asymmetric stance and pushing movement on the anticipatory and compensatory postural control

Yun-Ju Lee, Alexander S. Aruin *

University of Illinois at Chicago, Chicago, IL 60612, United States

ARTICLE INFO

Article history:
Accepted 30 September 2013
Available online 23 October 2013

Keywords:
Anticipatory and compensatory postural adjustments
Unilateral and bilateral movement
Asymmetric stance
Pushing

HIGHLIGHTS

- Asymmetry of stance and movement affect anticipatory and compensatory postural adjustments in pushing.
- The effect of asymmetry of stance is seen in the lower extremity muscle activity while the effect of asymmetry of the hand is seen in the trunk.
- Combined asymmetry may either help in maintenance of posture or endanger it.

ABSTRACT

Objective: To investigate effects of symmetric and asymmetric stance and pushing movement on anticipatory and compensatory postural adjustments (APAs and CPAs).
Methods: Ten healthy volunteers stood symmetrically (feet parallel) or asymmetrically (one foot forward and the other backward) and pushed a handle with both hands or right or left hand. Bilateral EMG activity of the trunk and leg muscles and center of pressure (COP) displacements in the anterior–posterior (AP) and medial–lateral (ML) directions were recorded and analyzed during the APAs and CPAs.
Results: Isolated asymmetry of stance was associated with larger muscle activity of the backward leg while isolated asymmetry of pushing movement induced larger trunk muscle activity on the contralateral side. A combined asymmetry of stance and pushing movement resulted in the increase or decrease of the thigh muscle activity and ML COP displacement depending on whether both asymmetries were induced on the same side of the body or on opposite sides.
Conclusions: Both isolated and combined asymmetries affect APAs and CPAs in pushing. Using combined asymmetry of stance and arm movement might be beneficial in performing pushing activity.
Significance: The outcome of the study provides a basis for studying postural control in individuals with unilateral impairment while performing daily tasks involving pushing.

1. Introduction

Maintenance of vertical posture in the field of gravity is the most common motor task humans perform in daily life. Many voluntary movements, especially performed fast, perturb body equilibrium due to the dynamic inter-segmental forces that may shift the center of mass outside of the base of support. The central nervous system (CNS) uses two types of activation of the trunk and leg muscles to counteract the effects of perturbations. The first type of muscle activations that are seen prior to the onset of voluntary arm or leg movement are based on prediction of the consequences of the planned motor action and termed anticipatory postural adjustments (APAs) (Aruin and Latash, 1995a, 1996; Belen'kii et al., 1967; Massion, 1992). The role of anticipatory adjustments is to counteract the predictable effects of an upcoming perturbation on body equilibrium. Another type of adjustments are observed in the activity of postural muscles after the actual perturbation of balance. These adjustments are initiated by sensory feedback signals and called compensatory postural adjustments (CPAs) (Alexandrov et al., 2005; Horak et al., 1996; Park et al., 2004). The CPAs' role is to restore the position of the center of mass after a perturbation has already occurred (Macpherson et al., 1989; Maki and McIlroy, 1996).

Both APAs and CPAs were studied in association with the fast arm raising or pointing movements (Aruin and Latash, 1995a;

* Corresponding author. Address: Department of Physical Therapy (MC 898), University of Illinois at Chicago, 1919 W. Taylor St., Chicago, IL 60612, Unites States. Tel.: +1 (312) 355 0904; fax: +1 (312) 996 4583.
E-mail address: aaruin@uic.edu (A.S. Aruin).

1388-2457/$36.00 © 2013 International Federation of Clinical Neurophysiology. Published by Elsevier Ireland Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.clinph.2013.09.036

Belen'kii et al., 1967; Stapley et al., 1999), leg movements (Lepers and Breniere, 1995) or releasing a load (Brown et al., 2003; Shiratori and Aruin, 2007), as well as while being exposed to an external perturbation (Santos and Aruin, 2008). These studies demonstrated that APAs are directionally specific (Aruin and Latash, 1995a) and depend on the characteristics of a motor action (Aruin et al., 2003; Aruin and Latash, 1995b). Similarly, perturbation direction-specific CPA patterns were observed in the leg and trunk muscles (Henry et al., 2001). Center of pressure (COP) displacements prior to the start of the perturbation were also documented in association to leg flexion (Yiou et al., 2011, 2012) and arm movement (Mochizuki et al., 2004).

Pushing an object is common in daily life, for example, when opening doors, moving strollers or grocery carts, etc. Pushing is also a widespread and commonplace handling activity in many manufacturing environments, warehouse and distribution settings, the service and delivery industry, and in patient-handling activities (Baril-Gingras and Lortie, 1995; Marras et al., 2009). Many activities involving pushing an object are performed using both hands or one hand only. Furthermore, while healthy individuals can choose whether to push an object with one or two hands, many individuals with unilateral impairments (e.g., stroke, cerebral palsy) are restricted to the use of their unaffected arm. To address such limitations, rehabilitation approaches are based on incorporating movements of both upper extremities. For example, repetitive bilateral or unilateral arm training is used in rehabilitation interventions for people with hemiplegia (Butefisch et al., 1995; Whitall et al., 2000).

While a number of studies investigated the biomechanical aspects of pushing task (Al-Eisawi et al., 1999; de Looze et al., 2000; Hoozemans et al., 2007), much less attention in the prior literature was paid to the motor control aspects of maintenance of posture during pushing. In a recent study involving pushing tasks performed in standing, it was reported that patterns of APAs and CPAs were affected by the changes in the symmetry of stance (Lee and Aruin, 2013). The outcome of this study highlighted the importance of taking into consideration asymmetry of standing. However, the previous study addressed the effect of a single asymmetry of stance only. At the same time, the presence of both, asymmetry of the body and asymmetry of the pushing movement, is common in daily activities. However, the effect of combined asymmetry in maintenance of vertical posture is much less studied.

The objective of the present study was to investigate the effects of changes in the symmetry of stance or/and movement on postural control during pushing. We hypothesized that when the asymmetry of pushing movement is induced, anticipatory and compensatory EMG activity of the trunk and leg muscles as well as medial–lateral COP displacements would be pushing hand-specific. Additionally, we hypothesized that when a combined asymmetry of stance and pushing movement is present, the asymmetry related changes in the APA and CPA EMG activity and medial–lateral COP displacements will be either additive or subtractive depending on whether both the asymmetries are induced on the same side of the body or on opposite sides.

2. Methods

2.1. Participants

Ten healthy volunteers (five females and five males, age 29.4 ± 3.9 years, height 170.7 ± 8.3 cm and weight 69.9 ± 14.4 kg) participated in the experiment. The study was approved by the University of Illinois at Chicago Institutional Review Board and all subjects signed a consent form.

2.2. Experimental procedure

The subjects were required to stand on a force platform and push an aluminum pendulum. The pendulum was attached to the ceiling and had the horizontal flat wooden handle connected to its free moving end. The handle (62 × 9 × 2 cm) had two marked areas indicating the position of the left and right palms while pushing; an extra 22.5 kg load was affixed to the opposite side of the handle. The symmetry of stance and pushing movement was varied so subjects were required to stand in three foot positions (each shoulder width apart): stance with feet parallel to each other (Ps), stance with right foot forward and left foot back (Rf), and stance with left foot forward and right foot back (Lf). The pushing of the pendulum was performed with bilateral hands (Bh), or right hand (Rh) and left hand (Lh) only. Thus, the nine experimental conditions included symmetrical stance and symmetrical (bilateral) pushing (PsBh), symmetrical stance and unilateral (asymmetrical) pushing (PsRh, PsLh), asymmetrical stance and symmetrical (bilateral) pushing (RfBh, LfBh) and asymmetrical stance and asymmetrical (unilateral) pushing (RfRh, LfRh, RfLh, LfLh) (Fig. 1). The required foot positions were marked with chalk on the top of the force platform. The subjects were instructed to stand upright with both their upper arms by the sides of their trunk at 90 degrees of elbow flexion and wrist extension with palms slightly contacting the pendulum handle. When performing unilateral pushing, the ipsilateral arm maintained the position as described above and the contralateral arm remained loosely by the side of the body. The task was performed in a self-paced manner by pushing the handle with the palm(s) using only trunk motion without wrist flexion and without taking a step or lifting the heels from the surface of the force platform. After the handle of the pendulum was pushed away, the subject was instructed to return to the starting position and wait for the next trial. The subjects performed several practice trials prior to the data collection to familiarize themselves

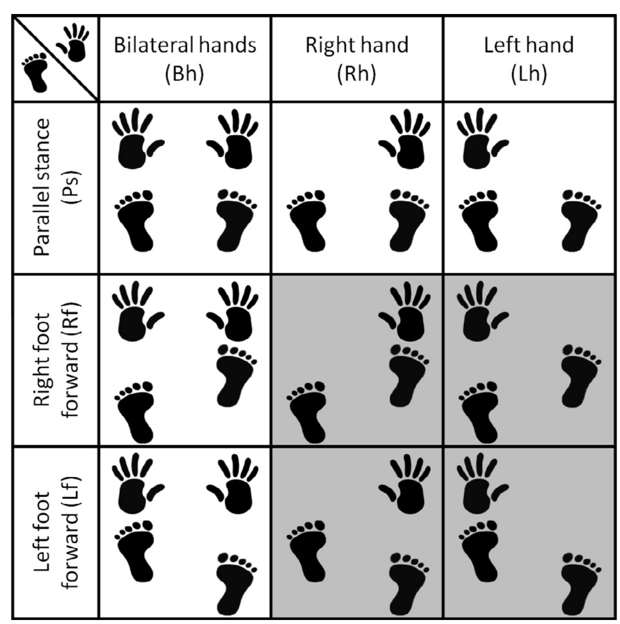

Fig. 1. Schematic representation of the experimental conditions. Abbreviations refer to changes in the stance and arm use: parallel stance (Ps), right foot forward stance (Rf), left foot forward stance (Lf), pushing with bilateral hands (Bh), pushing with right hand (Rh), and pushing with left hand (Lh). Conditions PsBh, RfBh, and LfBh refer to changes in the symmetry of stance. Conditions PsBh, PsRh, and PsLh reflect changes in the symmetry of arm movement. Conditions RfRh, RfLh, LfRh, and LfLh refer to changes in the asymmetry of both stance and arm movement and are highlighted with gray background.