Clinical Neurophysiology 128 (2017) 935–944

Contents lists available at ScienceDirect

Clinical Neurophysiology

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

Physiological arousal accompanying postural responses to external perturbations after stroke

C.L. Pollock [a], M.G. Carpenter [b], M.A. Hunt [a], A. Gallina [a,c], T.M. Vieira [c,d], T.D. Ivanova [e], S.J. Garland [e,*]

[a] Department of Physical Therapy, University of British Columbia, Vancouver, Canada
[b] School of Kinesiology, University of British Columbia, Vancouver, Canada
[c] Laboratorio di Ingegneria del Sistema Neuromuscolare (LISiN), Dipartimento di Elettronica e Telecomunicazioni, Politecnico di Torino, Italy
[d] Escola de Educação Física e Desportos, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil
[e] Faculty of Health Sciences, Western University, London, Canada

ARTICLE INFO

Article history:
Accepted 3 March 2017
Available online 18 March 2017

Keywords:
Stroke
Physiological arousal
Postural control
External perturbation

HIGHLIGHTS

- The physiological arousal responses to perturbations in standing post-stroke were established.
- People post-stroke show higher physiological arousal when anticipating perturbations than controls.
- Habituation to self-triggered perturbations was present in controls, but not in people post-stroke.

ABSTRACT

Objective: The purpose of this study was to examine simultaneously the level of physiological arousal and the postural response to external perturbations in people post-stroke compared to age-matched controls to build a more comprehensive understanding of the effect of stroke on postural control and balance self-efficacy.
Methods: Participants stood with each foot on separate force platforms. Ten applications of loads of 2% body weight at the hips perturbed the participant anteriorly under two conditions: investigator-triggered or self-triggered (total 20). Electrodermal activity (EDA; measurement of physiological arousal), electromyography (EMG) of the ankle plantarflexor muscles and anterior-posterior center of pressure measurements were taken pre-perturbation (anticipatory) and post-perturbation (response) and compared between the initial (first two) and final (last two) perturbations.
Results: Participants post-stroke demonstrated significantly higher levels of anticipatory EDA and anticipatory paretic plantarflexor EMG during both self- and investigator-triggered conditions compared to controls. Anticipatory EDA levels were higher in the final perturbations in participants post-stroke in both conditions, but not in controls. Habituation of the EDA responses post-perturbation was exhibited in the self-triggered perturbations in controls, but not in participants post-stroke.
Conclusions: Physiological arousal and postural control strategies of controls revealed habituation in response to self-triggered perturbations, whereas this was not seen in participants post-stroke.
Significance: Understanding the physiological arousal response to challenges to standing balance post-stroke furthers our understanding of postural control mechanisms post-stroke.

1. Introduction

Neuromuscular control of standing balance is known to be impaired after stroke (Garland et al., 2009). Response to surface translations have characterized the postural reactions of people post-stroke as being asymmetrical favoring the non-paretic leg (Marigold et al., 2004; van Asseldonk et al., 2006), accompanied by muscle activation which is delayed, and of decreased amplitude,

Abbreviations: EDA, electrodermal activation; ANS, autonomic nervous system; kg, kilogram; COM, center of mass; APCOP, anterior-posterior center of pressure; BM, body mass; EMG, electromyography; BOS, base of support; MG, medial gastrocnemius; LG, lateral gastrocnemius; SOL, soleus; CMSA, Chedoke McMaster Stroke Assessment Scale; CB&M, Community Balance and Mobility Scale; ABC, Activities-specific Balance Confidence Scale; HDsEMG, high-density surface electromyography; RMS, root mean square.

* Corresponding author at: Faculty of Health Sciences, Western University, Arthur & Sonia Labatt Health Sciences Bldg, Rm 200, London, ON N6A 5B9, Canada.
E-mail address: jgarland@uwo.ca (S.J. Garland).

http://dx.doi.org/10.1016/j.clinph.2017.03.008
1388-2457/

in the paretic limb with poor intra-limb muscle coordination (Badke and Duncan, 1983; Marigold and Eng, 2006). In particular, the plantarflexor muscles in people post-stroke demonstrate impaired responses to external perturbations (Pollock et al., 2015). The impairment in standing balance following stroke has also been shown to result in increased attention to postural control, proposed to be related to decreased balance confidence (or balance self-efficacy) (Brown et al., 2002; Orrell et al., 2009).

Mounting evidence suggests that physiological arousal modulated by the autonomic nervous system (ANS) may influence postural control (Horslen and Carpenter, 2011; Sibley et al., 2014). Physiological arousal can be measured indirectly by electrodermal activation (EDA), a measurement of skin conductance. Measurements of EDA have been used to examine changes in physiological arousal associated with changes in level of attention, cognitive effort, and emotion during tasks (Critchley et al., 2000). Changes in the level of attention and/or emotion surrounding maintenance of standing balance following stroke may result in increased levels of physiological arousal during tasks that threaten balance. This is important to consider as increased levels of arousal in general have been shown to alter postural control in healthy subjects regardless of the nature of the associated emotion (Horslen and Carpenter, 2011).

Perturbation tasks that manipulate the perception of threat and the knowledge of timing of a perturbation have demonstrated modulation of physiological arousal levels both in anticipation of a perturbation, and in response to perturbations (Sibley et al., 2008, 2010, 2014). Larger increases in physiological arousal in response to postural threat have been found in older adults than in young adults, which may be related to a change with aging in the perception of ability to recover from postural threat (Carpenter et al., 2006). Physiological arousal responses to perturbations have been shown to habituate in healthy subjects with repeated exposure to the same low-threat perturbation stimuli, whereas levels of arousal in anticipation of a perturbation remain stable (Sibley et al., 2010). Because the autonomic nervous system can be affected by stroke (Korpelainen et al., 1999), it is possible that attentional demands and emotional state may interact with balance-related neuromuscular impairments after stroke. Examining self-triggered versus investigator-triggered perturbations will uncover the effects of knowledge of and control over the timing of perturbation on both the physiological arousal and postural reaction to external perturbations following stroke.

The relationship between the perception of threat to standing balance and the postural strategy (e.g. increased postural muscle activity resulting in limited movement of the center of mass (COM) and the anterior-posterior center of pressure (APCOP)), adopted during a standing balance task has been established in healthy individuals (Adkin et al., 2002; Brown and Frank, 1997; Carpenter et al., 2001, 2006; Sibley et al., 2008). During external perturbations, healthy individuals demonstrate a lower COM and reduced APCOP displacement and velocity when expected perturbations are introduced under conditions of perceived risk to standing balance (Brown and Frank, 1997; Carpenter et al., 2001). These changes have been suggested to be secondary to a change in the postural control strategy in anticipation of a challenge to standing balance. Anticipatory postural strategies are associated with a tighter control of the COM and APCOP, which is suggested to ensure a more effective postural reaction to a perturbation, such that there is less displacement of the COM within the base of support (BOS) and therefore less risk of a fall (Brown and Frank, 1997; Horak et al., 1989; Horslen et al., 2013; Santos et al., 2010a, 2010b). Over a course of repeated perturbations, healthy subjects have been shown to demonstrate a habituated response to perturbation by the second trial whereas subjects with central nervous system impairment (Parkinson's Disease) showed a delayed habituation which has contributed to a decreased efficiency of motor learning (Nanhoe-Mahabier et al., 2012). During conditions of increasing level of challenge to standing balance, anticipatory postural strategies that limited body movement in response to external perturbations have been found in people post-stroke at lower levels of challenge than healthy controls (Pollock et al., 2015). How this postural strategy changes under conditions of perceived threat (external perturbations) and with repeated exposure is not known.

The purpose of this study was to examine simultaneously the level of physiological arousal and the postural response to external perturbations in people post-stroke compared to age-matched controls to build a more comprehensive understanding of the effect of stroke on postural control and balance self-efficacy. We hypothesized that: (1) people post-stroke would demonstrate higher levels of physiological arousal, as measured by electrodermal activation, and heightened ankle plantarflexor muscle activity than age-matched controls in anticipation of external perturbations; (2) physiological arousal and plantarflexor muscle activation would be less when both people post-stroke and healthy participants control the timing of the perturbation (self-triggered) vs. investigator-triggered perturbations of uncertain timing; (3) the anticipatory postural strategies used in participants post-stroke would result in less COM and APCOP displacement and velocity in response to perturbations compared to controls and; (4) repeated exposure to perturbations would result in habituation of levels of physiological arousal, COM and APCOP displacement and velocity, and plantarflexor muscle activity during self-triggered external perturbations in people post-stroke, whereas healthy controls would demonstrate habituation of postural reactions during both conditions.

2. Methods

Ten people with chronic stroke (>1 year post-stroke) and ten age-matched controls provided written informed consent to participate in this study. Participants post-stroke were recruited from local community stroke groups and controls were recruited from the university community, including a healthy aging fitness program (non-structured, self-directed activity levels). Individuals with hemiparesis post-stroke were included if they were ambulatory, with or without a walking aid, and could stand independently for a minimum of five minutes. Individuals were excluded if in addition to stroke, they had any health conditions that negatively impacted balance. Controls were included if they were free from neurological or musculoskeletal impairment which resulted in decreased balance. The study conformed to the standards set by the latest revision of the *Declaration of Helsinki* and was approved by the University of British Columbia Clinical Research Ethics Board.

The severity of motor impairment following stroke was measured at the foot and ankle using the Chedoke-McMaster Stroke Assessment (CMSA, (Gowland et al., 1993). The CMSA describes seven stages of motor recovery; 0/7 refers to flaccid paralysis and 7/7 refers to movement equated to a "normal" sensory-perceptual-motor system (Gowland et al., 1993). Both participants post-stroke and controls were assessed for ambulatory balance with the Community Balance and Mobility Scale (CB&M, /96; Howe et al., 2006; Knorr et al., 2010), and for balance related self-efficacy using the Activities-specific Balance Confidence Scale (ABC, /100; Botner et al., 2005; Myers et al., 1996).

2.1. Experimental protocol

Participants stood with their arms at their sides, barefoot with their feet shoulder-width apart, with each foot on a separate