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DOES AGING WITH A CORTICAL LESION INCREASE FALL-RISK: EXAMINING EFFECT OF AGE VERSUS STROKE ON INTENSITY MODULATION OF REACTIVE BALANCE RESPONSES FROM SLIP-LIKE PERTURBATIONS

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Abstract—We examined whether aging with and without a cerebral lesion such as stroke affects modulation of reactive balance response for recovery from increasing intensity of sudden slip-like stance perturbations. Ten young adults, older age-match adults and older chronic stroke survivors were exposed to three different levels of slip-like perturbations, level 1 (7.75 m/s^2), Level II (12.00 m/s^2) and level III (16.75 m/s^2) in stance. The center of mass (COM) state stability was computed as the shortest distance of the instantaneous COM position and velocity relative to base of support (BOS) from a theoretical threshold for backward loss of balance (BLOB). The COM position ($X_{COM/BOS}$) and velocity ($\dot{X}_{COM/BOS}$) relative to BOS at compensatory step touchdown, compensatory step length and trunk angle at touchdown were also recorded. At liftoff, stability reduced with increasing perturbation intensity across all groups (main effect of intensity $p < 0.05$). At touchdown, while the young group showed a linear improvement in stability with increasing perturbation intensity, such a trend was absent in other groups (intensity × group interaction, $p < 0.05$). Between-group differences in stability at touchdown were thus observed at levels II and III. Further, greater stability at touchdown positively correlated with anterior $X_{COM/BOS}$ however not with $\dot{X}_{COM/BOS}$. Young adults maintained anterior $X_{COM/BOS}$ by increasing compensatory step length and preventing greater trunk extension at higher perturbation intensities. The age-match group attempted to increase step length from intensity I to II to maintain stability however could not further increase step length at intensity III, resulting in lower stability on this level compared with the young group. Stroke group on the other hand was unable to modulate compensatory step length or control trunk extension at higher perturbation intensities resulting in reduced stability on levels II and III compared with the other groups. The findings reflect impaired modulation of recovery response with increasing intensity of sudden perturbations among stroke survivors compared with their healthy counter parts. Thus, aging superimposed with a cortical lesion could further impair reactive balance control, potentially contributing toward a higher fall risk in older stroke survivors.

Key words: reactive balance, hemiparesis, scaling, forward perturbations.

INTRODUCTION

Adverse events such as falls are a common cause of injury among long-term stroke survivors affecting the quality of life (Jørgensen et al., 2002). The incidence of falls among community-dwelling chronic stroke survivors ranges from 40% to 70% which is greater than 30% falls observed in their healthy counterparts (Mackintosh et al., 2005; Weerdesteyn et al., 2008). Although several stroke survivors demonstrate independent mobility during the chronic stage of recovery, persisting balance deficits contribute significantly toward occurrence of falls in this population (Harris et al., 2005). In addition, falls among community dwelling stroke survivors frequently occur due to sudden loss of balance from external perturbations during activities involving standing and walking (Batchelor et al., 2012; Schmid et al., 2013). Therefore, understanding factors that contribute toward falls from external perturbations would assist in designing effective fall prevention interventions for this population.

A rapid and effective compensatory stepping response is the first resort to restore balance and prevent a fall during sudden balance loss caused by a large magnitude perturbation in an upright position (McIlroy and Maki, 1996). The central nervous system (CNS) relies on the sensorimotor information to trigger a reactive response using feedback mechanism, while performing online modification of the reactive response depending on the perceived sensorimotor information (Bastian, 2008). As large external perturbations result in falls among older adults and neurologically impaired individuals, it is also desirable that CNS activates its defense mechanisms via feedback control to modify the reactive balance responses based on the perceived instability or threat. For example, it can either modulate the strategy itself by choosing between in-place responses for small perturbations (ankle vs. hip) (Horak and Nashner, 1986) or change-in-support responses (stepping strategy vs.

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Abbreviations: ANCOVA, analysis of covariance; BLOB, backward loss of balance; BMI, body mass index; BOS, base of support; CNS, central nervous system; COM, center of mass.

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reaching) for larger perturbations (Maki and McIlroy, 1997). For a given strategy, it can further modulate the magnitude of the response itself by parameterization of effector control (muscle forces and resulting kinematics). While earlier studies have examined modulation of in-place responses (Luchies et al., 1994; Burleigh and Horak, 1996; Marigold et al., 2004), only a few studies thus far have examined whether the reactive stepping response could be modulated during varying magnitudes of perturbation.

Thelen et al. (1997) reported that both young and older adults showed an increase in stepping velocity with increase in lean angle however not in step length. While young adults modulated the step length, older adults failed to further increase step length and resorted to executing multiple steps at higher lean angles. Luchies et al. (1994) also reported similar findings during backward cable pull perturbations such that at higher disturbances older subjects were unable to modulate step length as compared with young adults. Although, age-related differences were observed in step initiation times and step heights, neither of the groups showed modulation in these parameters. Previous studies have reported the modulation of step kinematics; whether or not individuals can successfully scale their dynamic center of mass (COM) stability by altering step kinematics, particularly during larger perturbations that could result in a fall, has not been examined systematically.

Both animal and human studies report that higher brain centers are involved in modulation of reactive balance responses (Beloozerova et al., 2003; Adkin et al., 2006). It is proposed that postural responses to sudden perturbation are regulated through a transcortical loop involving supraspinal pathways (Kimura et al., 2006; Pruszynski et al., 2011). Therefore, following injury to the cerebral cortex such as that seen in stroke one might expect impaired ability to modulate reactive balance responses. Previous studies have reported delayed postural muscle latencies of the paretic limb and altered timing of postural distal and proximal muscle contraction during external perturbations which may affect the interlimb co-coordination necessary for a compensatory stepping response (Di Fabio et al., 1986; Di Fabio and Badke, 1988; Marigold et al., 2004). These factors could further contribute toward impaired modulation of reactive balance responses as well, overall affecting the ability to regain balance from large external perturbations.

Others studies have examined stepping kinematics during single intensity large perturbations among chronic stroke survivors. These individuals present with delayed step initiation, poor COM stability control, shorter step length and more number of recovery steps as compared with their healthy counterparts when exposed to large magnitude perturbations (Mansfield et al., 2013; Salot et al., 2015). It is suggested that such impairments in balance responses may contribute toward falls among stroke survivors (Marigold and Eng, 2006; Inness et al., 2014). Also, age-related structural and functional decline could likely impact the recovery of balance function in stroke survivors, further increasing their risk of falls as compared with older adults without neurological conditions. While some literature exists to demonstrate deficits in reactive balance control among stroke survivors (Lin et al., 2014; Mansfield et al., 2015; Salot et al., 2015), the impact of cerebral injury on modulation of postural stability based on the perceived sensorimotor information during large slip-like perturbations is not known.

In this study, we examined whether aging with and without a cerebral lesion such as stroke affected modulation of reactive balance response for recovery from increasing intensity of sudden slip-like stance perturbations. We expected that as the perturbation intensity increases, both healthy controls (young and old) and stroke survivors would experience greater postural instability and degree of balance loss (multiple step responses). Based on some evidence on compensatory step modulation among young adults during varying magnitudes of cable pull and tether-release forward perturbations (Luchies et al., 1994; Hsiao-Wecksler and Robinovitch, 2007), we hypothesized that young adults would be able to recover balance at each perturbation intensity by demonstrating modulation of their reactive balance response, achieving greater postural stability at compensatory step touchdown with increasing perturbation intensity. Older healthy and stroke survivors as compared with young adults would show impaired modulation of reactive balance response for recovery with increase in perturbation intensity such that, they would demonstrate lower postural stability resulting from an inefficient compensatory step and trunk kinematics at higher perturbation intensities.

EXPERIMENTAL PROCEDURES

Participants

Young healthy adults (25.5 ± 3.80 years), older healthy adults (57.9 ± 6.40 years), and older chronic stroke survivors (>1 year post stroke, 56.00 ± 6.48) participated in the study. Each group comprised of ten participants. Stroke survivors with inability to stand independently without an assistive device, any cognitive impairment (Montreal cognitive assessment score <26/30), language impairment (Mississippi aphasia screening test score <71%), and subcortical stroke were excluded from the study. The presence of cortical stroke was confirmed from the individuals' physician at the time of enrollment into the study. Demographics of the participants in all three groups are presented in Table 1. Among the stroke survivors, balance and level of lower extremity impairment was assessed using clinical measures (see Table 2).

Testing protocol

The participants experienced slip-like perturbations in standing position on a motorized treadmill, ActiveStep (Simbex, Lebenon, NH). Participants assumed a comfortable stance on the treadmill with their feet shoulder width apart. A harness was donned to prevent participants' knees from touching the treadmill in case of