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Postural sway reduction in aging men and women: Relation to brain structure, cognitive status, and stabilizing factors

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Abstract

Postural stability becomes compromised with advancing age, but the neural mechanisms contributing to instability have not been fully explicated. Accordingly, this quantitative physiological and MRI study of sex differences across the adult age range examined the association between components of postural control and the integrity of brain structure and function under different conditions of sensory input and stance stabilization manipulation. The groups comprised 28 healthy men (age 30–73 years) and 38 healthy women (age 34–74 years), who completed balance platform testing, cognitive assessment, and structural MRI. The results supported the hypothesis that excessive postural sway would be greater in older than younger healthy individuals when standing without sensory or stance aids, and that introduction of such aids would reduce sway in both principal directions (anterior–posterior and medial–lateral) and in both the open-loop and closed-loop components of postural control even in older individuals. Sway reduction with stance stabilization, that is, standing with feet apart, was greater in men than women, probably because older men were less stable than women when standing with their feet together. Greater sway was related to evidence for greater brain structural involutional changes, indexed as ventricular and sulcal enlargement and white matter hyperintensity burden. In women, poorer cognitive test performance related to less sway reduction with the use of sensory aids. Thus, aging men and women were shown to have diminished postural control, associated with cognitive and brain structural involution, in unstable stance conditions and with diminished sensory input.

Keywords: Postural control; Posturography; Balance; Cerebellum; Brain; MRI; White matter hyperintensity; Sway; Age; Sex

1. Introduction

Upright stance, which typically becomes less stable with older age (Baloh et al., 2003; Collins et al., 1995; Rogind et al., 2003), is controlled by multiple factors. In addition to mechanical contributions from musculoskeletal and joint systems (for reviews, Butler et al., 2006; Winter et al., 2003), postural stability in normal healthy adults is affected by the availability and validity of visual, vestibular, haptic, and proprioceptive information that can provide a referential context for updating the body's location in extrapersonal space (Horak, 2006; Jeka and Lackner, 1994; Lackner and DiZio, 2005; Leibowitz and Shupert, 1985; Peterka and Loughlin, 2004). Useful integration of these informational sources depends, at least in part, on the integrity of brain structure and function and can be disturbed (Coppin et al., 2006; Shumway-Cook et al., 1997; Slobounov et al., 2005; Stelmach and Worringham, 1985) or enhanced (Rankin et al., 2000; Weeks et al., 2003) by cognitive factors. Failure to take advantage of stabilizing information can result in falling, which is one of the leading causes of morbidity and mortality in otherwise healthy aging individuals (Radebaugh et al., 1985; Tinetti et al., 1995a,b; Tinetti and Williams, 1998). Given the multifaceted nature of factors contributing to upright stance, efforts to identify mechanisms that can

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induce or ameliorate age-related postural instability require concurrent examination of these multiple variables.

Quantitative assessment of static posture with a balance platform provides opportunities to parse component processes of the postural control system and to test factors that influence balance (Bortolami et al., 2006; Collins and De Luca, 1993; Collins et al., 1995; Norris et al., 2005). The balance platform provides information on the center of pressure trajectory of an individual while standing and maintaining erect posture. The resultant data, rendered in a sway path stabilogram, represent the changes in pressure in two dimensions—anterior–posterior and medial–lateral. The length of the sway path over time is a classical measure of postural control. Another analysis approach is based on statistical biomechanical concepts, which treat the stabilogram as a system of coupled, correlated random walks that can be characterized by a diffusion coefficient.

As applied to the maintenance of erect static posture, the diffusion coefficient plot of successive temporal interval displacements devised by Collins and colleagues (Collins and De Luca, 1993, 1995b; Collins et al., 1995) reveals two distinct components, a short-term (i.e., short time interval, usually less than 2 s) and a long-term (i.e., greater than 2 s) component. The short-term component behaves like an open-loop control system that is mostly devoid of feedback, whereas the long-term component behaves like a closed-loop system with feedback based on afferent input. The open-loop component of postural control is little affected by attentional or other cognitive processes and is characterized by a steep-sloped activity gradient (Collins and De Luca, 1995b; Diener et al., 1989; Jeka et al., 1997). While brief, this component is prolonged in older relative to younger healthy individuals and can be a source of instability. The closed-loop component can be affected by internal and external perceptual information and cognitive demands (Raymakers et al., 2005) and typically has a long, relatively flat-sloped activity gradient, little affected by age (Collins et al., 1995). The steeper the slope of the diffusion plot components, the less tightly regulated and more random the control mechanisms. We used this diffusion model to parse the sway path in an effort to determine the extent to which age-related prolongation of the open-loop component could be shortened with sensory information and whether evidence for improvement in stability was related to measures of brain structural or functional integrity.

Brain dysmorphology associated with excessive sway in normal elderly individuals include ventricular enlargement and white matter hyperintensities (WMHI) (Tell et al., 1998), which typically occur in subcortical and periventricular brain regions (DeCarli et al., 2005; Jernigan et al., 1991). An early computed tomography study reported that elderly prone to falling had greater evidence of white matter disease than an age-matched group not prone to falling (Masdeu et al., 1989). More recent magnetic resonance imaging (MRI) studies report associations between WMHI burden and balance instability in older community-dwelling individuals (Guttmann et al., 2000; Starr et al., 2003; Tell et al., 1998), even when screened for cognitive impairment (Baloh et al., 2003). While nonspecific, both neuroradiological signs are markers of structural degradation occurring with normal aging and are also concomitants of declining cognitive function (DeCarli et al., 2001; Garde et al., 2000; Gunning-Dixon and Raz, 2000; Raz et al., 2007) or processing speed (Nebes et al., 2006; Schmidt et al., 1993; van den Heuvel et al., 2006). Which components of sway are associated with these brain markers of decline and whether sway during quiet standing can be ameliorated by sensory information and stance stabilization in healthy elderly with age-related ventricular or sulcal expansion or WMHI burden remain unanswered.

In addition to nonspecific brain correlates of impaired stability, specific correlates have been documented. For example, postural balance is impaired in individuals with pathology of the anterior superior vermis of the cerebellum, which is most commonly caused by chronic alcoholism [neuropathological evidence: Baker et al., 1999; Harper and Kril, 1993; Victor et al., 1989 and neuroimaging evidence: Gilman et al., 1990; Martin et al., 1995; Sullivan et al., 2000; Sullivan et al., 2006]. Functional imaging studies using positron emission tomography (PET) and single photon emission computed tomography (SPECT) have revealed activation of the cerebellar vermis in healthy, nonalcoholic men and women when engaged in postural control tasks. A PET activation study conducted after posturography was recorded in healthy adults assuming five different positions – from supine to sitting to standing – revealed greater regional blood flow in the anterior superior lobules of the vermis in participants with greater balance control while standing (Ouchi et al., 1999, 2001). Whether age-related decline in vermian volume is associated with postural instability or contributes to the more general indices of brain integrity (that is, WMHI and ventricular size) is not established.

The purpose of our study was to identify which component processes of static balance are differentially disrupted in healthy adults as they age. In addition, we tested whether identified components of imbalance could be ameliorated by external sensorimotor visual, tactile, and stance factors known to exert stabilizing forces in normal, healthy adults. Accordingly, we devised an experiment to manipulate vision, touch, and stance, while acquiring physiological measures of static postural control with a force platform, yielding sway paths and changes in pressure exerted independently in the anterior–posterior and medial–lateral planes relative to the individual (McCollum et al., 1996; Nashner and Peters, 1990; Sullivan et al., 2006). We tested the hypothesis that excessive postural sway would be greater in older than younger healthy individuals when standing without sensory or stance aids, and that introduction of such aids would reduce sway in both principal directions (anterior–posterior and medial–lateral) and in both the open-loop and closed-loop components of postural control even in older individuals. We also examined whether men and women would differ in ability to reduce sway with sensory aids or change in stance. Finally, we tested whether (1) greater sway related to greater evidence for