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PROPRIOCEPTIVE ACUITY PREDICTS MUSCLE CO-CONTRACTION OF THE TIBIALIS ANTERIOR AND GASTROCNEMIUS MEDIALIS IN OLDER ADULTS' DYNAMIC POSTURAL CONTROL

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Abstract—Older adults use a different muscle strategy to cope with postural instability, in which they 'co-contract' the muscles around the ankle joint. It has been suggested that this is a compensatory response to age-related proprioceptive decline however this view has never been assessed directly. The current study investigated the association between proprioceptive acuity and muscle co-contraction in older adults. We compared muscle activity, by recording surface electromyography (EMG) from the bilateral tibialis anterior (TA) and gastrocnemius medialis (GM) muscles, in young (aged 18–34) and older adults (aged 65–82) during postural assessment on a fixed and sway-referenced surface at age-equivalent levels of sway. We performed correlations between muscle activity and proprioceptive acuity, which was assessed using an active contralateral matching task. Despite successfully inducing similar levels of sway in the two age groups, older adults still showed higher muscle co-contraction. A stepwise regression analysis showed that proprioceptive acuity measured using variable error was the best predictor of muscle co-contraction in older adults. However, despite suggestions from previous research, proprioceptive error and muscle co-contraction were negatively correlated in older adults, suggesting that better proprioceptive acuity predicts more co-contraction. Overall, these results suggest that although muscle co-contraction may be an age-specific strategy used by older adults, it is not to compensate for age-related proprioceptive deficits.
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Key words: posture, aging, muscular coactivation, proprioception, EMG.

INTRODUCTION

Postural control is a complex neural process that requires sensory information from visual, proprioceptive and vestibular systems, all of which are subject to age-related decline (Horak et al., 1989). Decline in proprioceptive acuity is particularly relevant in this task, as this is the sensory modality with the greatest contribution in postural control (Peterka, 2002). Accordingly, a breadth of research has shown an association between low proprioceptive acuity and reduced postural control in older adults (Lord et al., 1991; McChesney and Woollacott, 2000; Madhavan and Shields, 2005; Goble et al., 2009). Such findings extend to mobility in general, with studies suggesting that proprioception is associated with functional performance, as assessed in tasks such as 'Timed up and go' and stairs ascent/descent in older adults (Hurley et al., 1998). Older adults also demonstrate changes in the proprioceptive strategy used. For example, similar to patients with lower back pain, older adults show reduced reliance on lower back proprioceptive information and increased reliance on ankle joint information (Brumagne et al., 2004). Brumagne et al. (2004) state that it is unclear whether the proprioceptive strategy changes or back pain is witnessed first in patients however, so this potentially maladaptive proprioceptive alteration could explain older adults' susceptibility to spinal pain. Additionally, it has been suggested that proprioceptive decline could lead to abnormal joint biomechanics during gait which could eventually lead to joint degeneration (Skinner, 1993). More importantly, lower limb proprioceptive acuity has been shown to be predictive of fall accidents (Lord et al., 1999).

In order to avoid postural instability and falls, the aging body is likely to develop compensatory strategies, for instance when exposed to changes in their base of support, older adults 'co-contract' or co-activate the muscles around the ankle joint (Laughton et al., 2003; Benjuya et al., 2004; Nagai et al., 2011, 2013; Nelson-Wong et al., 2012). Muscle co-contraction refers to the simultaneous contraction of the agonist and antagonist muscle about a joint, which is often associated with stiffening of the joint (Melzer et al., 2001; Tucker et al., 2008; Cenciarini et al., 2010). However, the efficacy of this strategy in terms of postural control appears to be context-dependent (Chambers and Cham, 2007a; Nagai et al., 2013). In terms of the lower limbs, muscle co-contraction has been interpreted as a compensatory strat-

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Abbreviations: 5XSTS, Five Times Sit to Stand; ANOVA, analysis of variance; AP, anterior–posterior; CCI, co-contraction index(es); COP, cenere of pressure; EMG, electromyography; GM, gastrocnemius medialis; MVCs, maximum voluntary contractions; RVCs, reference voluntary contractions; TA, tibialis anterior.

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egy for age-related decline in sensory acuity, especially proprioceptive acuity (Laughton et al., 2003; Benjuya et al., 2004; Madhavan and Shields, 2005), however the relationship between lower limb muscle co-contraction and proprioception has not been directly assessed by previous studies.

Age-related differences in lower limb muscle activation patterns in postural control tasks have been assessed by Benjuya et al. (2004). They showed that, in an upright standing task that was originally performed with eyes open, when visual information was withdrawn, young adults increased their postural sway more than older adults. This age difference in postural sway increase was accompanied by an age difference in muscle activation patterns, with older adults employing a different strategy from young adults whereby they co-contracted their lower leg muscles. The authors suggested that young adults increased postural sway in an attempt to gain more proprioceptive input from the lower limb muscles when one of the sources of sensory information (vision) was removed, whereas older adults did not increase their postural sway to the same degree, either due to an inability to utilize the additional lower limb proprioceptive input or a fear of reaching their limits of stability. Instead, they employed a muscle co-contraction strategy to prevent a further increase in postural sway by increasing the stiffness of the ankle joint. Benjuya et al. (2004) suggest that this stiffening is a compensatory response for degraded proprioceptive input. Alternatively, other authors have suggested that co-contraction may compensate for proprioceptive deficits by *increasing* proprioceptive information from muscle spindles (Laughton et al., 2003; Madhavan and Shields, 2005). Regardless of whether muscle co-contraction is employed in contrast to proprioceptive sense or in order to increase proprioceptive information, both of these arguments suggest that older adults who show reduced proprioceptive acuity would also show higher muscle co-contraction.

It is unclear how effective muscle co-contraction is as a compensatory postural strategy. On the one hand, it is also used by young adults when they are directly asked to minimize postural sway as much as possible, especially during difficult postural tasks (Reynolds, 2010). Similarly, both young and older adults increase muscle co-contraction in anticipation of a postural challenge, such as walking on a known slippery surface, and higher baseline co-contraction during walking on an unknown slippery surface is associated with less severe slips (Chambers and Cham, 2007b). This supports the proposition that it may be an adaptive strategy during postural instability. Additionally, evidence of its use in young adults suggests that it is not an age-specific strategy shift but may be a general strategy for larger postural challenges (Chambers and Cham, 2007b). Consequently, older adults may show higher muscle co-contraction as a result of their greater postural instability compared with young adults, as opposed to an effect of age.

Despite some evidence showing that muscle co-contraction can be an effective strategy, alternative evidence suggests that it is often a maladaptive strategy. For example, co-contraction is not associated with decreased postural sway in young adults (Reynolds, 2010). In contrast, evidence suggests that co-contraction is typically associated with increased postural sway in both young (Warnica et al., 2014) and older adults (Laughton et al., 2003; Nagai et al., 2011). For example, both Laughton et al. (2003) and Nagai et al. (2011) found that older adults demonstrated significantly higher levels of co-contraction in the lower limb muscles compared with young adults, and this was correlated with their postural sway during quiet stance. Additionally, Nagai et al. (2011) extended this association to functional reach distance. Although neither of these studies can infer whether muscle co-contraction precluded postural sway due to the correlative nature of the findings, Warnica et al. (2014) study provided further insight into this issue by asking young adults to actively co-contract the muscles around the ankle joint. Results showed that higher muscle co-contraction was associated with increased sway amplitude and frequency. The authors suggest that this may occur as the increased ankle stiffness may degrade proprioceptive feedback and thus participants turn to other postural strategies, such as a hip strategy. In line with this, other authors (Tucker et al., 2008) have suggested that the increase in ankle rigidity associated with co-contraction may impede adaptive responses to postural perturbations, which could explain the associations between higher co-contraction and a tendency to fall (Ho and Bendrups, 2002) and increased fall risk (Nelson-Wong et al., 2012). This suggests that in everyday life muscle co-contraction is an ineffective and risky postural strategy.

Together, evidence suggests that muscle co-contraction in postural control is more likely to be maladaptive. This observation raises the question: why have older adults developed a bias toward this strategy? One possibility is that co-contraction may result from age-related decline in proprioceptive acuity (Laughton et al., 2003; Benjuya et al., 2004; Madhavan and Shields, 2005), however little is known about the relationship between the two. A link between proprioceptive acuity and postural performance in older adults has been demonstrated by previous studies (Lord et al., 1991; Gauchard et al., 1999; McChesney and Woollacott, 2000; Madhavan and Shields, 2005). However, little is known about the relationship between proprioceptive acuity and lower limb muscle co-contraction during upright stance. Madhavan and Shields (2005) assessed the relationship between proprioceptive acuity and balance measures, such as standing/single-limb standing with eyes open/closed in young and older adults. Proprioceptive acuity was assessed using a passive ('dynamic') position sense task, during which the authors reported significant use of muscle co-contraction in the lower leg. However, the relationships between muscle co-contraction, proprioceptive acuity and balance measures were not examined.

The main aim of the present study was to assess the relationship between proprioceptive acuity and lower limb muscle co-contraction in young and older adults' postural control. The studies reviewed above suggest that muscle co-contraction may be a compensatory strategy for proprioceptive acuity decline, thus, co-contraction and

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