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Effect of aging on dynamic postural stability and variability during a multi-directional lean and reach object transportation task

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ABSTRACT

A "reach and transport object" task that represents common activities of daily living may provide improved insight into dynamic postural stability and movement variability deficits in older adults compared to previous lean to reach and functional reach tests. Healthy young and older, community dwelling adults performed three same elevation object transport tasks and two multiple elevation object transport tasks under two self-selected speeds, self-paced and fast-paced. Dynamic postural stability and movement variability was quantified by whole-body center of mass motion. Older adults demonstrated significant decrements in frontal plane stability during the multiple elevation tasks while exhibiting the same movement variability as their younger counterparts, regardless of task speed. Interestingly, older adults did not exhibit a tradeoff in maneuverability in favour of maintaining stability throughout the tasks, as has previously been reported. In conclusion, the multi-planar, ecologically relevant tasks employed in the current study were specific enough to elucidate decrements in dynamic stability, and thus may be useful for assessing fall risk in older adults with suspected postural instability.

1. Introduction

The risk of falling is an ever-present challenge faced by elderly populations in activities of daily living (ADL). While external threats (e.g. slips, trips) present an obvious threat to stability, the loss of balance during self-generated movement has also been associated with falls in older adults. A study of community dwelling older adults found that a substantial proportion of falls occurred during tasks such as carrying an object, reaching or leaning (Nachreiner, Findorff, Wyman, & Mccarthy, 2007). Such actions as lean and reach, bending, stooping, and high reach tasks reportedly account for a substantial proportion of ADL in community dwelling older adults (Clark, Czaja, & Weber, 1990). As such, incorrect weight transfers and control of stability during these volitional movements represents a likely cause of falls, both in community dwelling older adults (Berg, Alessio, Mills, & Tong, 1997) and older adults residing in long-term care facilities (Robinovitch et al., 2013).

Reaching studies involving older adults have included clinical upper limb movement tests of stability, for example the functional reach (FR) balance test (Duncan, Weiner, Chandler, & Studenski, 1990) in healthy older adults (Jonsson, Henriksson, & Hirschfeld, 2003), as well as individuals with stroke (Smith, Hembree, & Thompson, 2004) and Parkinson's disease (Behrman, Light, Flynn, & Thigpen, 2002). Despite wide use of the FR test, inconsistent results have limited its usefulness as a clinical tool to assess balance and fall risk. While some studies have shown predictive validity of the FR in identifying recurrent falls (Duncan, Studenski, Chandler, & Prescott, 1992), others have shown that FR does not adequately measure dynamic balance (Wernick-robinson, Krebs, & Giorgetti, 1999), and suggest that it is a weak measure of stability limits (Jonsson et al., 2003). While reaching itself is an action routinely performed by individuals on a daily basis, this action is more often accompanied by a subsequent grasp and lift or transport of an object. To our knowledge, no studies to date have investigated reaching and transporting an object with a fixed base of support (BOS) in an ecological environment (e.g. transferring an object in a kitchen from countertop to cupboard height). A greater understanding of older adult stability and balance when performing these ecological reach and transport tasks may provide critical insight into decrements in balance control with aging.

In fact, very few studies using a functional reach test to assess balance have measured dynamic postural stability during the upper limb reaching task. The primary focus of this earlier work

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has been on the outcome measure of displacement between the start and end points of the reaching limb (Bennie et al., 2003; Lynch, Leahy, & Barker, 1998; Weiner, Duncan, Chandler, & Studenski, 1992) although some of this past work has reported peak displacements of the center of pressure (COP) to infer stability limits (Jonsson et al., 2003), displacement between the vertical projection of the center of mass (COM) and COP at the reach completion (Wernick-robinson et al., 1999) or has focused on the preparatory phase of movement via quantification of anticipatory postural adjustments (Bleuse et al., 2006). While these measures provide important insight into dynamic postural control during an upper limb reach task, they do not account for the COM or COP relation to the BOS, the COM or COP speed, or are limited to specific time points during the task (i.e. preparatory phase or end point of the FR).

In 2005, Hof, Gazendam & Slinke proposed a modeling of the time-to-contact (TTC) as a measure of whole body stability during complex dynamic tasks, such as reaching and object transport. TTC is a measure of the amount of time it would take the current motion of COM to travel outside the BOS. The TTC has been identified as a control parameter optimized by the CNS during a stepping balance response (Hasson, Van emmerik, & Caldwell, 2008), and may be an important control parameter and indices of stability during self-generated dynamic movement. Along with any measure of stability, an important aspect of movement control is the variability of the movement action. This is especially important in individuals at risk of falling, such as older adults as previous literature has shown that these individuals can exhibit a trade-off of maneuverability in favour of stability when executing complex tasks (Huang & Ahmed, 2011). When this occurs, older adults may complete the given task at hand with a safe level of stability, but this over prioritization may result in the inability to counteract unforeseen perturbations to the system, which could ultimately result in a loss of balance.

The **primary purpose** of this study therefore was to quantify age related changes in stability and movement variability when performing dynamic ADL tasks. It is expected that measures of stability throughout the entirety of the reach and transport task along with measures of movement variability will reveal deficits in dynamic postural control in healthy older adults. The ADLs in this study involved upper body movements over different heights either at the *same elevations* or at *multiple elevations*. The same elevation tasks were leaning to reach and move an object forwards, leftwards, or rightwards, with the object kept at the same height. The multiple elevation tasks were moving an object along the body midline across different heights (below and above countertop height). We **hypothesized** that older adults would have decreased stability compared to younger adults, indicated by decreased TTC (Hof, Gazendam, & Sinke, 2005) and increased inter-trial variability. A **secondary purpose** of this study investigated whether instructed increased movement speed affects movement stability and variability, as older adults report frequently the feeling of being rushed or are in a rush when detailing the circumstances of their fall (Nachreiner et al., 2007). Thus, we **hypothesized** that healthy older adults would exhibit decrements in stability and variability when performing at fast-paced conditions, while younger adults would be less affected by performing the tasks at a fast pace.

2. Methods

2.1. Participants

The present study recruited participants from the university student population and the community at large, with a total of nine young healthy adults (5 females and 4 males) and ten healthy older adults (4 females and 6 males) taking part in the experimental protocol (see Table 1 for characteristics). All participants were free of any self-reported neuromuscular or skeletomuscular diseases, did not take any medication that would adversely affect motor control and execution nor cognition. All older adults who participated in this study had never experienced a fall; participants were instructed that we considered a fall as "unintentionally losing balance and coming to rest on the ground or a lower level" [modified from Lord & Dayhew, 2001]. The Falls Efficacy Scale (FES; see Table 1) (Kempen et al., 2008) was administered to characterize fear of falling, while the Waterloo Handedness Questionnaire (Bryden, Pryde, & Roy, 2000) ensured all subjects were right hand dominant. To comply with University ethics guidelines for the present study, all older adults completed the Mini Mental Status Exam (MMSE) (Cockrell & Marshal, 2002) strictly as a measure to ensure competency in giving informed consent for this study; a score of 25 or less was used as an additional exclusion criterion. This study complied with ethics approval granted by the University Research Ethics Board.

2.2. Experimental setup and protocol

Participants executed a series of object transport tasks that involved either an elevation change (up/down) or same level directional change (forward/left/right); all tasks were done with a fixed base of support (BOS; i.e. no stepping or lifting of the feet). The object to be transported was a full soup can (10 cm tall × 6.7 cm in diameter; mass = 0.5 kg). A custom made, adjustable object stand was constructed (Fig. 1) with a total of six platforms: four platforms at standard countertop height ((36 inches; 91.44 cm); forward, left, right, and initial positions), one platform at twice countertop height (high condition, 72 inches (182.88 cm)) and one platform at half countertop height (low condition, 18 inches (45.72 cm)). The closest middle platform was the initial position, and could be reached without hip flexion. These heights matched an ecologically relevant environment and ADL tasks that require movement of the upper body while maintaining a fixed base of support. Participants were positioned 40% of body height away from the closest platforms (high, initial, and low), with the furthest three countertop height platforms positioned 50% of body height away (required a lean-to-reach action).

Two main object transport tasks were executed by participants: (1) same-elevation: object transport from the initial position to one of the three platforms (forward, left, and right) at the same elevation, (2) transporting the object from either the high or low platforms to the initial platform. All object transports were completed with the dominant, right arm while maintaining a barefoot shoulder-width stance; foot location was kept consistent between trials by tracings of the feet. Prior to data collection,

Table 1
Physical characteristics of our sample population including age (years), height (cm), and weight (kg). Falls Efficacy Scale scores and total group trial errors for both younger and older adults are also reported. Note, mean and standard error values are presented in the table. The FES is scored on 10 questions with numerical answers given between 1 (absolute confidence) and 10 (no confidence whatsoever), resulting in a score out of 100 with a lower score indicating a high confidence in maintaining balance.

	Older Adults	Younger Adults
Age (years)	78.4 ± 2.4	23.9 ± 0.7
Height (cm)	173.4 ± 2.7	169.3 ± 2.6
Weight (kg)	72.5 ± 3.0	67.2 ± 4.8
Falls Efficacy Scale	10.6 ± 0.4	10.3 ± 0.2
Trial Errors	6	1