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Influence of non-spatial working memory demands on reach-grasp responses to loss of balance: Effects of age and fall risk

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ABSTRACT

Reactive balance recovery strategies following an unexpected loss of balance are crucial to the prevention of falls, head trauma and other major injuries in older adults. While a longstanding focus has been on understanding lower limb recovery responses, the upper limbs also play a critical role. However, when a fall occurs, little is known about the role of memory and attention shifting on the reach to grasp recovery strategy and what factors determine the speed and precision of this response beyond simple reaction time. The objective of this study was to compare response time and accuracy of a stabilizing grasp following a balance perturbation in older adult fallers compared to non-fallers and younger adults while loading the processing demands of non-spatial, verbal working memory. Working memory was engaged with a progressively challenging verb-generation task that was interrupted by an unexpected sideways platform perturbation and a pre-instructed reach to grasp response. Results revealed that the older adults, particularly those at high fall risk, demonstrated significantly increased movement time to handrail contact and grasping errors during conditions in which non-spatial memory was actively engaged. These findings provide preliminary evidence of the cognitive deficit in attention shifting away from an ongoing working memory task that underlies delayed and inaccurate protective reach to grasp responses in older adult fallers.

1. Introduction

One fundamental issue in balance rehabilitation concerns the extent to which individuals can dedicate cognitive resources to meet postural demands. The widespread use of dual task paradigms, in which postural and cognitive tasks are performed simultaneously, has revealed interference effects demonstrating the importance of cognition to balance and gait control [1–6]. However, such dual task paradigms, although useful in testing the cognitive capacity for divided attention, do not address the integrative role of executive cognitive control in reactive balance tasks. Moreover, since most of our daily thoughts are spontaneous in nature and appear to tax non-spatial executive resources, it is essential that non-spatial demands be incorporated into cognitive studies of reactive balance control.

In light of these considerations, the rapid reach to grasp stabilizing response to a sudden loss of balance brings forth particular challenges to executive cognitive function that has not yet been fully explored. Although older adults are more likely to use the reach to grasp strategy, they also demonstrate more errors in their grasping attempts compared to younger adults [7–9]. The known visuospatial working memory demands of an efficient grasp response [7] highlight the potential importance of shifting attention from the ongoing internally directed thoughts that occupy a majority of our mental processes. Therefore, known age-related declines in attention shifting between working memory processes [10,11] may underlie reduced grasp accuracy in older adults who are at risk of falling.

The objective of this study was to compare response time and accuracy of a stabilizing grasp following perturbation in older adult fallers compared to non-fallers and young adults while loading non-spatial working memory. It was hypothesized that, compared to older non-fallers and young adults, older fallers would demonstrate differences in reaction time and time to handrail contact while non-spatial working memory was actively engaged. Secondly, we hypothesized that older fallers would demonstrate increased frequency of grasping error and variability in reaching direction.

2. Methods

A total of 33 participants were divided into the following three groups: (1) 12 healthy older adult fallers (70 ± 5 yrs), (2) 11 healthy

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age-matched older non-fallers (69 ± 4 yrs), and (3) 10 healthy young adults (25 ± 2 yrs). All participants were recruited from a sample of convenience and older adults were classified as a 'faller' if they had experienced a minimum of one unintended fall within the prior 12 months. A fall was defined as "unintentionally coming to the ground or some lower level other than as a consequence of sustaining a violent blow, loss of consciousness, sudden onset of paralysis as in stroke or an epileptic seizure" [12]. Exclusion criteria included significant musculoskeletal, vestibular, or neurological impairments, and a Mini-Mental State Exam (MMSE) score <24, suggestive of dementia [13]. Demographic data for all participants are reported in Table 1. This study was approved by the University Institutional Review Board (IRB) and all participants provided written informed consent prior to participation.

The ActiveStep Simbex (Simbex Inc.) was used to conduct all laboratory balance tests. Participants were asked to stand laterally on the belt in a comfortable, quiet standing position with eyes focused straight ahead on a large red 'X'. A 40 × 40 cm restraint box was lined with foam and secured around each participant's feet to prevent stepping. One handrail was placed to the right and another to the left at a distance of 30% of each subject's height from midline. Handrails were 89 cm high, which is within the Occupational Safety and Health Administration (OSHA) standards of 76–94 cm (Section 1926.1052). An overhead safety harness was used to reduce the risk of falling, but did not restrict movement during the perturbations.

Using custom profiles of the ActiveStep, an individualized perceived loss of balance threshold was assessed for each participant. Thus, we could identify the perturbation necessary for a true reactive arm response as opposed to a voluntary response cued by platform movement. The acceleration of the initial platform perturbation (i.e. level 1) was 1.5 m/s^2 for a distance of 0.06 m. Higher levels of perturbation were achieved by acceleration increases of 2 m/s^2 to the point at which the participant was observed to naturally grasp the handrail to restore balance. The response was confirmed over three trials and testing level was set two levels above threshold.

Four different perturbation conditions were administered, with eight trials for each condition. Instructions were as follows: "As soon as you feel the platform begin to move, quickly grab the one rail that will help you recover your balance most effectively. Do not take a step". Conditions were as follows: (1) *Predictable*: non-random order of right or left perturbations; (2) *Unpredictable*: random order of right and left perturbations; (3) *Unpredictable with verb generation*: a verb generation task was interrupted by a random order of right or left perturbations. A member of the study team read concrete nouns aloud at 2 s intervals to which the subject was to generate an associated verb as quickly as possible; (4) *Unpredictable with 1-back verb generation*: a 1-back verb generation task was interrupted by a random order of right or left perturbations. Participants generated a verb for the noun stated 1-prior to the current noun as quickly as possible. Practice trials were provided without perturbation prior to conditions 3 and 4 until five verbs were generated without error. Instructions to prioritize one task over the other (i.e. balance versus cognitive) once the perturbation occurred were not provided. Also, in this initial investigation, the progression from least to most cognitively challenging conditions was blocked and not random to avoid possible confusion from alternating different cognitive task demands. The possibility of habituation was ruled out by comparing the first and last two trials under each condition.

Table 1
Demographic data for all groups[a].

	Young adults (n = 10)	Non-fallers (n = 11)	Fallers (n = 12)
Age, years	24.5 ± 2.12	68.5 ± 4.08	69.83 ± 4.73
Weight, kg	73.5 ± 10.9	80.64 ± 14.19	81.83 ± 18.74
Height, cm	172.2 ± 11.12	168.36 ± 11.59	166.33 ± 5.99
Body mass index (kg/m^2)	24.59 ± 4.22	28.49 ± 4.64	29.57 ± 6.64
Handedness (R:L)	9:1	7:4	12:0
Education level (years)	17	14	16
Mini-mental scale (/30)	n/a	30	29
Number of falls (1:2:multiple)	n/a	n/a	5:3:4
Perturbation threshold (m/s^2, m)	13.5, 0.06	9.5, 0.06	13.5, 0.06

[a] Data are reported as mean ± SD unless otherwise noted.

Reach responses were analyzed as reaction time, movement time, and grasp accuracy (Fig. 1). *Reaction time* was defined as the time from the onset of platform perturbation to time of initial arm response (defined as EMG onset of anterior or middle deltoid). *Movement time* was calculated as the latency from initial arm response to handrail contact that resulted in a stabilizing grasp. Handrail contact was measured using an attached custom contact sensor. Raw EMG data was collected using six wireless dual electrodes (Noraxon U.S.A., Inc) taped onto bilateral anterior deltoid (AD) and middle deltoid (MD) muscles, parallel to muscle fiber alignment. Data was collected at a set sampling rate of 1500 Hz for 7 s with 100 ms analog output time and 10–500 Hz Butterworth band pass filtering for cut-off frequency. EMG onset time was determined using a customized Matlab program (Mathworks, Inc) that identified the time at which the EMG signal rose three standard deviations above baseline, maintained for at least 25 ms. Since data was collected for both middle and anterior deltoid, the faster of the two muscles per trial for each participant was used. Moreover, since we were interested in responses related to the direction of perturbation, movement time analyses only included opposite and same side responses (defined below).

Grasp error frequency and direction of reach to grasps were also determined. A *grasp error* was defined as a collision, overshoot, or undershoot of the handrail. A *stabilizing grasp* was either a full grasp (five digit grasp) or a partial grasp (less than five digits grasp). Pictorial classifications were used to determine grasp type using video captured during the balance task. Three members of the research team independently confirmed each trial classification. Grasp error frequency was calculated as the percent of total

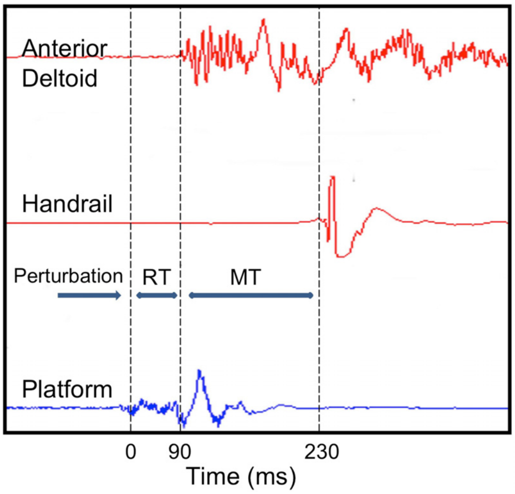

Fig. 1. Example EMG trace depicting reaction and movement time. Reaction time (RT) was defined as the time from the onset of platform movement to EMG onset of grasping arm (anterior or middle deltoid). Movement time (MT) was defined as the time from EMG onset to handrail contact. Platform displacement is depicted along the bottom trace.