Gait & Posture 44 (2016) 143–148

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Normal aging increases postural preparation errors: Evidence from a two-choice response task with balance constraints

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ARTICLE INFO

Article history:
Received 2 April 2015
Received in revised form 26 October 2015
Accepted 1 December 2015

Keywords:
Aging
Balance
Response conflict
Partial errors
Inhibition

ABSTRACT

Correlational studies indicate an association between age-related decline in balance and cognitive control, but these functions are rarely addressed within a single task. In this study, we investigate adult age differences in a two-choice response task with balance constraints under three levels of response conflict. Sixteen healthy young (20–30 years) and 16 healthy older adult participants (59–74 years) were cued symbolically (letter L vs. R) to lift either the left or the right foot from the floor in a standing position. Response conflict was manipulated by task-irrelevant visual stimuli showing congruent, incongruent, or no foot lift movement. Preparatory weight shifts (PWS) and foot lift movements were recorded using force plates and optical motion capture. Older adults showed longer response times (foot lift) and more PWS errors than younger adults. Incongruent distractors interfered with performance (greater response time and PWS errors), but this compatibility effect did not reliably differ between age groups. Response time effects of age and compatibility were strongly reduced or absent in trials without PWS errors, and for the onset of the first (erroneous) PWS in trials with preparation error. In addition, in older adults only, compatibility effects in the foot lift task correlated significantly with compatibility effects in the Flanker task. The present results strongly suggest that adult age differences in response latencies in a task with balance constraints are related to age-associated increases in postural preparation errors rather than being an epiphenomenon of general slowing.

1. Introduction

Adult human aging often is associated with decline in balance and postural control [1–4] as well as reductions in cognitive control, especially in tasks with increased complexity [5], or requiring inhibition of prepotent responses [6]. Correlational and dual-task studies provide evidence that links between sensorimotor performance and cognitive function increase with advancing adult age [3,7]. Moreover, deficits in executive control in older adults have been related to balance problems, cognitive-balance interference, as well as fall risk [8–11]. In this study, these functional domains are integrated in a choice-response task with balance constraints and different levels of stimulus-response compatibility, to assess the interaction between age-related deficits in balance and cognitive control within a single task.

Lifting one foot from the floor or starting to walk from a standing position is an apparently simple, everyday motor act, which however requires integrating the focal movement of lifting a foot with balance requirements for maintaining an upright posture [12]. As lifting one foot from the floor changes the base of support, it is usually preceded by a preparatory weight shift (PWS) consisting of a weight transfer to the opposite limb. This weight shift can be detected as a transient *increase* of the ground reaction force (GRF) of the to-be-lifted leg, accelerating the body to the opposite side. Older adults have been found to show increased step latencies and postural preparation errors (PWS inconsistent with the required response) during gait initiation and directional stepping, especially when participants could not preselect the stepping leg [13,14]. Combining a lateral stepping task with a stimulus-response compatibility paradigm, Sparto, and collaborators found increased PWS errors for incongruent compared to congruent stimulus-response conditions, and this compatibility effect was more pronounced in older adults [15].

We recently introduced a whole-body response paradigm manipulating response conflict in terms of automatic imitation tendencies [16]. Participants in an upright bipedal standing

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http://dx.doi.org/10.1016/j.gaitpost.2015.12.002
0966-6362/

position were cued symbolically (letter L vs. R) to lift the left or right foot from the floor. Response conflict was manipulated by visual distractors showing congruent, incongruent or no foot lift movement (as a baseline condition). Response times and number of PWS errors were increased in the incongruent condition compared to the congruent condition.

The aim of this study was to assess whether and how these results from a stimulus-response compatibility paradigm with balance constraints [16] generalize to older adults. The study thereby also tests the generalizability of results found in gait initiation or stepping paradigms [13,15] to a simpler foot lift movement. Specifically, we assess to what extent (1) older adults show degraded task performance compared to young adults (in terms of response latencies and PWS errors), (2) compatibility effects differ between young and older adults, (3) response latency differences between age groups and between conditions are related to PWS errors, and (4) inter-individual differences in compatibility effects are related across tasks.

2. Methods

2.1. Participants

Sixteen healthy young and 16 healthy older adults (eight women per group) participated after providing written informed consent. All participants were right-handed and reported no medical history of neurological or balance-related conditions or chronic pain. Older participants were screened for dementia [17]. Detailed participant information can be found in Table 1. Experimental data from the young adults have been published in a previous study [16].

Participants received a compensation of 10 Euro per hour. This study was approved by the Ethics Committee of the Max Planck Institute for Human Development.

2.2. Setup and data acquisition

Ground reaction forces (GRF) were measured separately for each foot by two force plates (9286AA, Kistler Instruments, Wintertur, Switzerland). Foot positions were marked by two pieces of carpet (30 cm by 12 cm), placed at a lateral distance of 10 cm and an angle of 10°. Visual stimuli were back-projected to a screen placed 150 cm in front of participants. The size of the visual stimuli on the screen was 72 × 54 cm (symbol cue: 7 × 8 cm), presented 40 cm above the floor.

Kinematic data were recorded using an optical motion capture system (Vicon, Oxford, UK) with four reflective markers at relevant landmarks (toes, sacrum, C7). Kinematic and force plate data were recorded synchronously at sampling rates of 100 Hz and 1000 Hz, respectively.

2.3. Task and procedure

For the main experimental task, participants stood with each foot on one of the force plates in the designated areas, facing the projection screen. They were instructed to lift one foot from the floor as quickly as possible (to a height about mid-way between ankle and knee of the other leg) in response to a *symbolic* or *movie cue* (described below). Based on pilot experiments, the beginning of each trial was initiated automatically when the GRF asymmetry between left and right foot remained below 20% of the participant's body weight (BW) for at least 300 ms.

Between trials, the lower legs of a person were displayed on the projection screen (Fig. 1, top panel). Cue presentation started after a pseudorandom delay (500–900 ms). In the *symbol cue* condition, the letter L or R was shown between the feet for 566 ms, the task being to lift the corresponding (left or right) foot. In the *movie cue* condition, an animated sequence showing a foot lift was presented (two intermediate images for 33 ms, final image for 500 ms), and the task was to lift the foot on the same side as the model on the screen. Presentation duration of the intermediate images (33 ms) was doubled relative to a previous study on finger movements [18] in line with the greater complexity and duration of the foot lift movement. Stimuli from both cueing conditions were presented separately (baseline condition, i.e. symbolic cue without movement distractor, or vice versa) or in a congruent (Fig. 1, bottom left) or incongruent (Fig. 2, bottom right) combination.

The *symbol cue* (A) and *movie cue* (B) conditions were presented in four blocks in an ABBA or BAAB sequence, counter-balanced across participants. Each block consisted of 60 trials (20 baseline/congruent/incongruent) in pseudo-random order, resulting in 240 experimental trials per participant. Twelve practice trials were provided before the first and second block (first occurrence of each Cue Type condition). Experimental programming was done in Matlab R2011b (MathWorks) using the PsychToolbox [19,20].

Additional measures of balance and cognitive control were assessed prior to the main task/experiment: Balance performance was independently assessed as one-leg standing time (up to 30 s, best of two trials), for both legs and both with open and closed eyes. Inhibition of incompatible distractor information was assessed in a standard (manual) Flanker task [21], with accuracy and response time in correct response trials as dependent measures.

2.4. Data analysis

Custom-written Matlab routines were used to analyze force plate and kinematic data, as described below. Trials were excluded (2.9% of all trials) if the force asymmetry at cue onset exceeded 20% BW, if the foot lift occurred earlier than 200 ms or later than 2000 ms after cue onset, or if the wrong foot was lifted.

Table 1
Participant characteristics (age, weight, height, physical activity), performance (MMSE, one-leg standing), and interference effects (foot lift and Flanker). Values are indicated as group means (SD). Statistical tests for age differences (two-sample t-tests) are reported where appropriate.

Test/measure	Young adults	Older adults	Age effect
Age (years)	25.4 (3.2)	67.4 (4.7)	
Weight (kg)	70.9 (10.9)	74.8 (9.1)	$t(30) = 1.12$, $p = 0.27$
Height (cm)	177.3 (12.0)	171.9 (12.5)	$t(30) = -2.0$, $p = 0.055$
MMSE [17]	–	28.4 (1.3)	
Physical activity [33]	8.25 (1.61)	9.06 (0.84)	$t(30) = 1.19$, $p = 0.09$
One-leg standing, eyes open (s)	29.9 (0.25)	24.7 (6.3)	$t(30) = -3.27$, $p = 0.003$
One-leg standing, eyes closed (s)	22.7 (8.2)	4.4 (2.7)	$t(30) = -8.54$, $p < 0.001$
Foot lift time interference, incongruent–congruent (ms)	75.4 (41.3)	103.3 (59.4)	$t(30) = 1.54$, $p = 0.13$
PWS error interference, incongruent-congruent (%)	33.8 (20.4)	35.3 (19.1)	$t(30) = 0.22$, $p = 0.83$
Flanker RT interference, incongruent–congruent (ms)	80.3 (29.7)	95.7 (46.5)	$t(29) = 1.09$, $p = 0.28$
Flanker accuracy interference, incongruent–congruent (%)	−3.0 (2.9)	−11.7 (6.4)	$t(29) = -4.84$, $p < 0.001$