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Attentional costs of visually guided walking: Effects of age, executive function and stepping-task demands

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ABSTRACT

During walking, attention needs to be flexibly allocated to deal with varying environmental constraints. This ability may be affected by aging and lower overall executive function. The present study examined the influence of aging and executive function on the attentional costs of visually guided walking under different task demands. Three groups, young adults ($n = 15$) and elderly adults with higher ($n = 16$) and lower ($n = 10$) executive function, walked on a treadmill in three conditions: uncued walking and walking with regular and irregular patterns of visual stepping targets projected onto the belt. Attentional costs were assessed using a secondary probe reaction time task and corrected by subtracting baseline single-task reaction time, yielding an estimate of the additional attentional costs of each walking condition. We found that uncued walking was more attentionally demanding for elderly than for young participants. In young participants, the attentional costs increased significantly from uncued to regularly cued to irregularly cued walking, whereas for the higher executive function group, attentional costs only increased significantly from regularly cued to irregularly cued walking. For the group with lower executive function, no significant differences were observed. The observed decreased flexibility of elderly, especially those with lower executive function, to allocate additional attentional resources to more challenging walking conditions may be attributed to the already increased attentional costs of uncued walking, presumably required for visuomotor and/or balance control of walking.

1. Introduction

Accurate foot placement, especially under challenging environmental conditions, is essential to prevent slips, trips or misplaced steps that are common causes of falls in elderly individuals [1]. Various intrinsic factors contribute to successful stepping performance, including higher-level cognitive functions, such as attention [2]. Assessing residual processing capacity during visually guided walking helps to reveal the amount of attention required for accurate stepping. Excessive cognitive effort invested in foot placement can limit an individual's ability to attend to environmental hazards leading to increased fall risk. Dual-task paradigms have demonstrated that increased age is associated with greater attention allocation to foot placement during walking [3], particularly in elderly individuals with a higher risk of falling [4].

While the ability to adapt stepping behavior has been assessed in relation to various environmental constraints such as an obstacle [5] or a curb [6], other studies have exploited visual or auditory cues to assess gait adaptability, especially in neurological [7], orthopedic [8] and geriatric [9,10] populations. Compared to uncued walking, attentional costs increased when steps were adjusted to external cues, with visual cues (projected stepping stones) demanding more attention than auditory cues (metronome beeps) [10]. This result highlights the predominant role of visual information in gait control, particularly in environments that demand visually guided step adjustments [11].

Several factors may influence the relationship between visually guided step adjustments and associated attentional demands. To unravel the effect of age on this relationship, Peper et al. [10] examined the attentional demands of visually cued walking in young and elderly adults. The attentional demands

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were higher for elderly participants for all cued and uncued conditions, but the increase in attentional demands over the conditions was comparable for both age groups. In addition, decreased functioning of specific cognitive domains, such as executive function (EF) [12] may affect age-related deficits in attentional demands of walking. EF represents coordinated action of cognitive processes such as attention, planning, response monitoring and response inhibition, and is essential for successful performance of goal-directed activities in a flexible manner [13]. Impairment of one or more of these processes may decrease the ability to efficiently deal with changes in walking task demands [13]. Indeed, EF is a predictive factor for fall risk among older adults [14] and is associated with stepping performance, particularly under increased environmental complexity [15]. A third important factor in visually guided stepping is terrain complexity [11]. Visually guided stepping becomes less accurate with increased environmental complexity [8] and this effect is more prominent in elderly individuals [16].

To date, the roles of age, EF, and terrain complexity in visually guided walking have mostly been studied in relation to stepping performance [8,15,16]. In the current study we focused on how these factors influence the attentional demands of visually guided walking. To this end, we recruited elderly participants (considerably older than those in [10]) with lower EF (LEF) or higher EF (HEF) and a group of young adults. Because attentional demands of walking appear to be minimal at one's preferred speed and gait pattern [17,18], all participants walked at their self-selected comfortable walking speed under three conditions: uncued walking and walking onto regular and irregular patterns of stepping targets, with the patterns of stepping targets being based on each individual's preferred gait pattern. In this way we created comparable conditions for all participants. We used a probe reaction time (RT) task to assess the associated attentional demands and hypothesized that RT would be higher for cued than uncued walking, in particular when the stepping stones were irregularly spaced. These differences were expected to be larger for elderly participants, especially for those with LEF, compared with young participants. In line with previous findings [3], we also expected higher attentional costs for the elderly groups compared to young participants for uncued walking. Furthermore, visually guided stepping was hypothesized to be less accurate for walking onto an irregular than a regular sequence of stepping targets, again most markedly so for older adults and particularly those with LEF.

2. Materials and methods

2.1. Participants

Fifteen young adults and two groups of elderly adults with either HEF ($n = 16$) or LEF ($n = 10$) participated (see Table 1). Exclusion criteria were self-reported cardiovascular or cardiopulmonary problems, orthopedic conditions, uncorrected visual or auditory impairments, neurological diseases, other conditions limiting mobility, use of walking aids and Mini Mental State Exam (MMSE) score below 19 (actual scores all $\geq$26; Table 1). The older adults were selected from a cohort of 148 elderly who had previously participated in the Fall Risk Assessment in Older Adults (FARAO, MOVE Research Institute Amsterdam). We invited participants based on their Trail Making Test (TMT) B/A score [19], using the upper and lower 33% thresholds to select participants for the LEF ($B/A > 2.78$) and HEF ($B/A < 1.91$) groups, respectively. The experimental protocol was approved by the local ethics committee and participants signed informed consent before the experiment commenced.

2.2. Instrumentation

An instrumented treadmill with an embedded force platform (ForceLink, Culemborg, The Netherlands) allowing for online detection of gait events and gait characteristics [20] was used in all experimental walking conditions. A sequence of stepping targets (length: participant's shoe length, width: 10 cm) could be projected onto the treadmill, approaching the participant at belt speed. Thanks to a 1.2 m projection board attached to the front of the treadmill, several upcoming steps were visible to the participant (Fig. 1). Stimulus–response RT was assessed using a custom-made stimulus vibrator (pulse duration: 300 ms, attached to the non-dominant hand's wrist) and a response button (sampling rate: 1000 Hz, held in the dominant hand). All participants wore a safety harness while walking on the treadmill.

2.3. Pre-experimental procedure

All participants first practiced treadmill walking at various speeds for approximately 7–10 min, depending on their prior experience. Subsequently, participants were familiarized with walking onto a sequence of regularly and irregularly spaced

Table 1
Participants' characteristics per group.

	Young adults ($n = 15$)	Elderly adults ($n = 25$)		Group comparisons	
		Higher EF[a] ($n = 15$)	Lower EF ($n = 10$)	Statistics[b]	p-Value
Age (yr)	22.7 (2.5)	76.0 (6.6)	74.5 (7.5)	$F_{2,37} = 399.30$	<0.001
Height (m)	1.77 (0.10)	1.69 (0.08)	1.70 (0.06)	$F_{2,37} = 3.92$	0.03
Weight (kg)	72.3 (11.7)	68.7 (8.3)	72.9 (9.3)	$F_{2,37} = 0.73$	0.49
Sex (female/male)	8/7	11/4	5/5	$X^2(2) = 1.81$	0.40
MMSE	–	29.1 (1.0)	28.8 (1.6)	$t(23) = 0.51$	0.62
Executive function					
TMT					
Part A (s)	20.9 (5.2)	42.9 (11.1)	43.2 (11.9)		
Part B (s)	42.3 (11.5)	76.7 (28.9)	103.1 (34.9)		
B/A ratio	2.04 (0.39)	1.76 (0.34)	2.43 (0.64)	$F_{2,37} = 6.53$	0.004
SCWT interference (s)	26.1 (9.0)	49.1 (17.5)	72.1 (38.2)	$F_{2,36} = 12.17$	<0.001
Timed Up & Go (s)	–	8.7 (2.4)	9.0 (1.5)	$t(23) = -0.32$	0.75
Comfortable walking speed (km/h)	4.3 (0.4)	3.4 (0.7)	2.9 (0.9)	$F_{2,37} = 13.10$	0.001
Baseline reaction time (ms)	265.4 (49.1)	367.2 (84.1)	325.7 (73.5)	$F_{2,37} = 7.99$	0.001

Note: Values are presented as mean (SD) unless stated otherwise. TMT, Trail Making Test; SCWT, Stroop Color-Word test.

[a] Data of one person in the HEF group were removed in view of outliers in ΔRT performance.

[b] Overall group comparisons, involving 2 levels for MMSE and Timed Up & Go and 3 levels for all other outcome measures.