Age-related differences in locomotor targeting performance under structural interference

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Abstract

Objective: to determine if there are age-related differences in locomotor targeting (LT) performance and step length (SL) regulatory behaviour under structural interference.

Methods: forty older (n = 20, mean age = 77.9) and younger (n = 20, mean age = 25.2) participants walked 11.6 m while stepping on a target positioned at the 9.5 m point. Participants completed seven trials under each of three conditions, including the control (C) (no structural interference), low structural interference (L) and high structural interference (H). The structural interference conditions required participants to engage in LT while simultaneously verbally identifying letters that were visually presented on one of two monitors. One monitor was located near the target (low interference), while the other monitor was elevated to require participants to direct their gaze further away from the target to identify a letter (high interference). Outcome measures included LT error, SL, SL variability and the distribution of SL adjustment.

Results: structural interference had a detrimental effect on the LT accuracy of the older group (2.75 cm mean increase in absolute error) but not on the younger group (1.05 cm mean increase in absolute error), even though the interference caused the older group alone to adopt a more conservative gait pattern involving shorter SLs. The older participants exhibited shorter mean SL with each increase in structural interference (conditions C vs. L, P = 0.004; conditions L vs. H, P = 0.050), whereas the younger participants’ mean SL did not differ across conditions. The manner in which older and younger participants distributed SL adjustment across the steps in advance of the target did not differ.

Conclusions: the results confirmed that LT demands more attention from older adults than it does from younger adults, and revealed that a consequence of this age difference is a decline in LT accuracy among older adults. The study implicates age-related impaired visual attention switching as a potential source of impaired walking performance among older adults.

Keywords: attention, structural interference, step length, locomotor targeting, dual-task, elderly

Introduction

The majority of falls in older adults occur during walking [1], and a critical component of stability during walking is locomotor targeting (LT) [2–4]. LT involves positioning a foot at a specific location on the support surface, and represents a common challenge faced by locomoting humans. For example, LT plays a prominent role in obstacle negotiation, as a primary reason for failed obstacle avoidance is incorrect foot placement before an obstacle [3]. LT involves the regulation of several gait parameters, the most prominent of which is step length (SL) [5].

Dual-task studies, which examine the extent of attention resource sharing [6], have indicated that walking requires attention [5, 7, 8], and more so for older adults than younger adults [7]. Several authors have speculated that dual-task situations could negativity influence LT performance [9, 10], especially in older persons [11, 12]. However, the role of attention in LT has rarely been studied directly using an interference criterion [13]. Using a visual reaction time task to impose structural interference, Sparrow et al. [12] found that reaction times increased when walking involved targeting, revealing that attention demand was greater in LT than unconstrained walking. Moreover, slower
visual reaction times were associated with the LT task in older participants. Sparrow et al. concluded that in gait tasks involving targeting, competing visual information could either ‘lead to declines in gait task performance, increasing the risk of a fall or, alternatively, allocating increased attention resources to the gait task may reduce the response time to a hazard’ (p. 970). Unfortunately, because Sparrow et al. did not evaluate gait task performance, their speculation that it might be influenced by having to respond to a secondary stimulus remains just that – speculation.

LT is often preceded by visual fixation of stepping targets [14–16], typically occurring two steps in advance of a target [17]. According to Henderson [18], eye movement to fixate a target represents an attention shift, with the information obtained used for locomotor planning and execution [16, 19]. Older adults look sooner to stepping targets and exhibit longer fixation times than younger adults [16, 20, 21], suggesting that older individuals need more time to plan accurate stepping movements.

Although the literature suggests that LT demands more attention from older adults, the consequences of this age-related change remain uncertain. The first purpose of this study was to investigate Sparrow et al.’s [12] speculation that competing visual information could lead to declines in LT performance among older adults. LT also involves anticipatory strategies for integrating visual and kinesthetic sensory input that results in modulation of SL during approach to a target [22]. Thus, the second purpose of our study was to determine if there are age-related differences in the SL adjustment associated with LT.

Our participants performed an LT task under each of the three structural interference conditions, including the control (no interference), and two dual-task conditions (low interference and high interference). The interference conditions were expected to have a greater detrimental effect on the LT performance of older adults than younger adults. Moreover, we expected older adults alone to alter their SL adjustment strategy in the presence of structural interference, probably by delaying SL adjustment (shifting SL adjustment closer to the target).

Methods

Participants

The investigation involved two groups, one consisting of 10 men and 10 women 18–36 years of age (n = 20, mean age = 25.2, SD = 5.3), and a second group consisting of 10 men and 10 women 70–85 years of age (n = 20, mean age = 77.9, SD = 4.2). Participants were (a) able to walk unaided, (b) free of serious medical and mobility problems, (c) not visually impaired and (d) independent and community dwelling. For additional participant characteristics and a justification of the sample size, see Supplementary data available in Age and Ageing online, Appendix 1. Our Institutional Review Board approved the study, and all participants provided informed consent.

Procedures

A participant walked 11.6 m from a standing start at his or her preferred speed. While walking, participants stepped on a white 1.2 m wide × 0.29 m deep target positioned at the 9.46 m point. Participants stepped on the target as accurately as possible with either foot (i.e. positioned the toe as close to the distal edge of the target as possible), and did so without deviating from their preferred walking speed any more than necessary. Participants performed five practice trials followed by seven actual trials under each of three conditions. The 21 trials consisted of a random presentation of the three conditions. The control condition (C) involved LT only. Conditions L (low interference) and H (high interference) introduced structural interference. Under conditions L and H, participants had to target as accurately as possible while simultaneously verbally reporting the letters intermittently visually presented on one of the two identical 16 in. monitors, a low monitor (condition L) and a high monitor (condition H) (see Figure 1). Both monitors were located adjacent to the right side of the walkway, 1.04 m beyond the target. The low and high monitors were positioned 0.1 and 1.8 m above the ground, respectively. The high monitor was more interfering because of its greater visual eccentricity relative to the target. A new random letter was presented randomly every 1–2 s. during a trial. Participants identified an average of 6.1 letters per trial. On average, the older adults identified one letter for every 2.9 steps walked, while the younger group identified one letter for every 2.8 steps. Walk times for the third to fifth practice trials were averaged. Participants were asked to maintain that average walk time (±5%) throughout the experiment. This ensured that participants engaged in simultaneous walking and targeting, and could not abandon the locomotor component in order to focus solely on targeting.

Prior to each trial, participants were informed of the condition under which the trial would be performed. Trials were repeated if participants failed to correctly identify any of the letters presented. Among the older group, a total of eight trials (<2% of all trials) across six participants had to be repeated, whereas the younger participants did not repeat any trials. Fall risk was managed by having participants wear a harness suspended from a trolley at the ceiling. Participants rested for 1 min between trials, and for 2 min following trials 7 and 14. Neither group demonstrated evidence of fatigue.

Measurement

A research assistant using a tape measure in conjunction with 1 cm intervals marked on the floor measured LT error (i.e. the position of the toe relative to distal edge of the target). To measure toe-to-target distances for footfalls
prior to the targeting footfall, participants were videotaped from the side using a JVC GR-DVL9800 camera recording at 60 Hz and a shutter speed of 1/250 s, and the videotapes were digitised (SIMI Reality Motion). SL was calculated from the toe-to-target distances via subtraction. SL variability was computed as the coefficient of variation of SL for each trial. The percentage of SL adjustment executed on each of the final six steps in advance of the target was derived from measures of intra-participant foot positioning variability across trials (SD of toe-to-target distance). For additional information regarding the computation of SL adjustment, as well as the validity and reliability of the measurement systems, see Supplementary data available in *Age and Ageing* online, Appendix 2.

**Statistical analysis**

Data were subjected to repeated measures ANOVA with one random effect (participant) and two fixed effects (age group and interference condition). Post hoc analyses consisted of Bonferroni adjusted multiple comparisons. To determine whether there were age differences in the distribution of SL adjustment, data were subjected to repeated measures ANOVA with one random effect (participant) and three fixed effects (age group, interference condition and step). Because the SL adjustment data were in the form of proportional responses and thus subject to the non-constant variance problem, data were first arcsin-square-root-transformed. An alpha level of .05 was used for the statistical tests.

**Results**

**Absolute targeting error**

Mean absolute targeting error is presented in Table 1. A significant main effect for age was found, $F(1,38) = 11.71, P = 0.001$, with the younger and older groups exhibiting means of 2.7 cm (SD = 1.2) and 4.7 cm (SD = 2.3), respectively. That is, older participants missed the target by an average of 4.7 cm while the younger participants missed the target by an average of 2.7 cm. There was also a significant age by condition interaction, $F(2,38) = 4.99, P = 0.012$. Post hoc comparisons revealed significant differences in targeting error between young and old under both conditions L and H, $P = 0.005$ and $P = 0.027$, respectively, but not under condition C, $P = 0.254$. Post hoc comparisons focusing on the older participants revealed significant differences in targeting error between conditions C and L, $P = 0.0003$ and C and H, $P = 0.0003$, but not between conditions L and H, $P = 0.670$. Post hoc comparisons focusing on the younger participants did not reveal differences in targeting error among the three conditions (C vs. L, $P = 0.135$, C vs. H $P = 0.168$, L vs. H $P = 0.641$). For information regarding the differences in the proportion of old and young participants who contributed to the least accurate trials, see Supplementary data available in *Age and Ageing* online, Appendix 3.

**Step length**

Mean SL is presented in Table 1. A significant main effect for age was found for SL, $F(1,38) = 14.46, P = 0.001$, with the younger and older groups exhibiting means of 72.4 cm (SD = 6.4) and 63.0 cm (SD = 1.9), respectively. There was also a significant age by condition interaction, $F(2,38) = 5.41, P = 0.008$. Post hoc comparisons revealed significant differences in SL between young and old under all three conditions: C vs. L, $P = 0.006$, L vs. H, $P = 0.001$ and H vs. C, $P = 0.001$. The older participants exhibited significantly shorter SL with each increase in interference (conditions C vs. L, $P = 0.004$; conditions L vs. H, $P = 0.050$), whereas the younger participants’ SL did not differ across conditions.

**SL variability**

Mean coefficient of variation of SL is presented in Table 1. A significant main effect for age was found for the coefficient of variation of SL, $F(1,38) = 3.93, P = 0.050$, with the younger and older groups exhibiting means of 5.5% (SD = 1.46) and 6.4% (SD = 1.21), respectively. However,
there was no significant age by condition interaction, $F(2,38) = 0.34$, $P = 0.713$.

**Distribution of SL adjustment**

The distribution of SL adjustment is presented in Figure 2A–C. There was no significant age by step interaction $F(5,35) = 2.11$, $P = 0.086$, indicating that the percentage of SL adjustment executed on the steps in advance of the target did not differ between young and old participants.

**Discussion**

The fact that there was no age difference in absolute LT error under the control condition suggests that LT performance under a single task condition is generally well maintained in old age. Structural interference, however, had a detrimental effect on the LT accuracy of older adults, but not on younger adults. This finding confirms that LT demands more attention from older adults than it does from younger adults, and it reveals that a consequence of this age-related difference is a decline in LT accuracy among older adults, just as Sparrow et al. [12] had speculated.

Among older participants, the average difference in absolute targeting error between the control and interference conditions was 2.75 cm. Although this difference was statistically significant, is an LT error of 2.75 cm functionally meaningful? In locomotor tasks with nominal accuracy requirements, an LT error of 2.75 cm may seldom influence safety or functionality. Conversely, navigation of natural terrain regularly involves targeting tasks that impose quite severe and consequential accuracy constraints, such as targeting a stair tread or a patch of dry pavement on an otherwise icy sidewalk. Performance of such tasks could be seriously impaired by a 2.75 cm increase in LT error. LT also plays a prominent role in obstacle negotiation, as a primary reason for failed obstacle avoidance is incorrect foot placement before an obstacle [3]. It is possible that a structural interference-induced 2.75 cm increase on foot placement error could be detrimental by increasing the likelihood of obstacle contact.

Why did the older participants suffer a performance decrement under structural interference, whereas the younger participants did not? The answer is likely related to the role of vision in both object identification and adaptive locomotion. Because letter identification relies
on the focal visual system, involving only central vision [23], participants’ gaze had to be directed at the monitor to identify a letter. However, determining target location relies on the ambient visual system, which involves the entire visual field [23]. While gaze need not be directed precisely at a target to ascertain its approximate location, obtaining precise information about the position of one’s foot relative to the target is aided by target fixation [14]. As our participants approached the target, all of them were observed to repeatedly switch their gaze between the target and the monitor. Older adults are known to require longer target fixations to plan accurate stepping movements [16, 20, 21], and therefore, slower visual attention switching was the likely source of the impaired LT performance exhibited by the older participants when faced with structural interference. However, visual eccentricity of letter presentation, which was greater under condition H than L, did not influence targeting error. Apparently, it was visual attention switching alone that demanded attention, not the extent to which participants had to redirect their gaze.

Structural interference caused an increase in targeting error in the older participants but not the younger despite the fact that the older participants alone adopted a more conservative gait pattern involving shorter SLs. A decrease in SL is consistent with strategies for improving postural control [24]. For example, older adults have been shown to adopt a more conservative stepping strategy during obstacle negotiation than younger persons, as indicated by shorter SLs [25]. It is interesting to note that whereas the older participants’ absolute targeting error in conditions L and H did not differ, their SLs in conditions L and H did differ, suggesting that condition H was perhaps more structurally interfering than condition L after all.

When walking is challenged by LT, SL adjustment begins in advance of the target or obstacle [10]. The eye movement literature suggests that target fixation usually occurs two steps in advance of a stepping target [17] and that fixation onset is indicative of an attention shift [18] and initiation of locomotor planning and execution [16, 19]. However, our analysis revealed that both groups of participants began to make SL adjustment an average of six steps from the target, and under all conditions completed 27–37% of total SL adjustment prior to the penultimate step (see Figure 2). It is clear that target fixation is not a prerequisite for SL adjustment and/or that target fixation occurs much earlier than two steps from the target.

Although there appeared to be a tendency for structural interference to cause the older participants to shift some SL adjustment from the final step to the penultimate step more so than the younger group (see Figure 2), the distribution of SL adjustment over steps in advance of the target did not differ statistically between young and old participants. It is noteworthy, however, that the tendency observed is contrary to our hypothesis that older adults would delay SL adjustment in the presence of structural interference. If anything, the older participants may have hastened SL adjustment in the presence of structural interference.

Limitations and conclusions

Our study had several limitations. First, the letter identification may have induced some capacity interference. Second, requiring participants to approximate normal walking speed throughout the experiment may have resulted in less within-participant walking speed variability than one might see in real world LT behaviour. Third, the harness used to manage fall risk may have made participants less cautious than they would otherwise have been. Fourth, we did not measure the speed of letter identification. Finally, the older participants in this study were representative of a relatively healthy subgroup of older adults. It is possible that SL regulatory behaviour in frail older adults might differ more dramatically from that of younger persons.

We can conclude the following.

- LT accuracy under a single-task condition was generally well maintained in old age.
- Structural interference had a detrimental effect on the LT accuracy of older adults, but not on younger adults.
- Structural interference caused older adults to shorten SL but had no effect on SL variability, whereas neither was affected in younger persons.
- The way in which SL adjustment was distributed in LT was little affected by old age.

Future research will extend this paradigm to examine the effect of more severe structural interference on LT performance. Moreover, we will examine whether structural interference differentially affects the locomotor stability of older and younger persons, independent of targeting accuracy.

Key points

- This study showed that locomotor targeting accuracy under a single-task condition was generally well maintained in old age.
- Structural interference caused an increase in absolute locomotor targeting error in the older participants but not younger, despite the fact that older participants alone adopted a more conservative gait pattern involving shorter SLs.
- Older adults should be advised to exercise caution in dual-task locomotor situations where locomotor targeting accuracy is a requirement.

Supplementary data

Supplementary data mentioned in the text is available to subscribers in Age and Ageing online.
References


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Conflicts of interest

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