Published paper
Harley, C., Wilkie, R.M. and Wann, J.P. (2009) *Stepping over obstacles: Attention demands and aging.* Gait & Posture, 29 (3). pp. 428-432.
http://dx.doi.org/10.1016/j.gaitpost.2008.10.063

Stepping Over Obstacles: Attention Demands and Aging

Clare Harley[a], Richard M. Wilkie[b*] and John P. Wann[c]

a. Leeds Institute of Molecular Medicine, University of Leeds, UK

b. Institute of Psychological Sciences, University of Leeds, UK

c. Department of Psychology, Royal Holloway, University of London, UK

*Corresponding author at:
Institute of Psychological Sciences, The University of Leeds, Leeds, LS2 9JT
E-mail: r.m.wilkie@leeds.ac.uk (R.M.Wilkie);
Tel: +44(0)113 343 6681; Fax: +44(0)113 343 5749

Acknowledgements

Research supported by UK EPSRC grants: GR/R26979/01, GR/S86358 and EP/D055342/1

Abstract

Older adults have been shown to trip on obstacles despite taking precautions to step carefully. It has been demonstrated in dual-task walking that age-related decline in cognitive and attentional mechanisms can compromise postural management. This is yet to be substantiated during obstacle negotiation when walking. Forty-six healthy volunteers (aged 20-79 years) stepped over obstacles in their path whilst walking and performing a verbal fluency task. Using 3D kinematic analysis we compared obstacle crossing during single (obstacle crossing only) and dual-task (obstacle crossing with verbal task) conditions. We grouped the participants into three age groups and examined age-related changes to cognitive interference on obstacle crossing. During dual-task trials, the 20-29 and 60-69 groups stepped closer to the obstacles prior to crossing, increased vertical toe-obstacle clearance, and had reduced gait variability. In these two groups there was a small dual-task decrease in verbal output. The 70-79 group applied similar dual-task stepping strategies during pre-crossing. However, during crossing they showed reduced vertical toe-to-obstacle clearance and increased variability of obstacle-to-heel distance. Additionally, this group did not show any significant change to verbal output across trials. These results suggest that with advanced age, increased cognitive demands are more likely to have a detrimental impact on motor performance, leading to compromised safety margins and increased variability in foot placement. We conclude that younger adults utilise a posture-preserving strategy during complex tasks but the likelihood of this strategy being used decreases with advanced age.

Key words: Aging, obstacle negotiation, dual-task, human locomotion, cognition

Introduction

It is estimated that one in three older adults fall each year and this figure includes those who are healthy and active [1]. In this age group, a large proportion of falls are caused by stepping on or tripping over obstacles [2]. Whilst it is accepted that a number of cognitive functions decline with advanced age, it is still unclear how such age-related changes impact on the control of complex motor skills such as walking and stepping. The relationship between cognitive activity and posture control can be examined using dual-task methods that apply a cognitively demanding task during a posture task (see Woollacott & Shumway-Cook [3] for a review). These studies suggest that concurrent cognitive activity can interfere with motor control, and that interference is greater in older adults [4, 5]. These findings have important implications for complex motor tasks that require large cognitive resources, as the addition of a cognitive task may lead to misallocation of resources, and impaired motor control. For example, a number of studies have shown that older adults who would typically be classified as independently mobile under single-task conditions demonstrate limitations to walking as the task becomes more complex [6-8].

Despite the apparent interplay between cognition and posture, the nature of dual-task interference on posture is not always clear. When walking, dual-task interference tends to manifest as reduced performance (e.g. reduced velocity, shorter stride length) [9]. In upright standing it can be difficult to interpret dual-task effects because concurrent cognitive activity has been shown to both increase and decrease postural sway [10, 11]. Few studies have examined the effect of concurrent cognitive activity or ageing on foot placement when negotiating obstacles [12-14]. The results from dual-task walking studies suggest that concurrent cognitive performance should have a detrimental effect on the control of foot placement during obstacle crossing. There has been some indication of this in the literature [12-14] but these results are not conclusive. For example, Chen et al [13] observed participants walking and avoiding a suddenly appearing band of light projected on the walkway. Concurrently participants completed a verbal reaction task, responding when a red light appeared at the end of the walkway. The results showed increased foot-light contacts when completing the verbal reaction task, especially for older adults. Since the reaction task in this study directed visual attention from the immediate walkway, it is not possible to infer that increased attention demands led to impaired stepping control. Schrodt et al [12] demonstrated that a concurrent memory task altered stride positioning when crossing obstacles but reported no other changes to gait. Brown et al [14] examined changes to a verbal reaction time task during obstacle crossing. The reaction task was presented before or during obstacle crossing. They reported increased reaction times in young and older adults when the task was presented before obstacle crossing. Additionally, the older adults had increased reaction times when the task was presented during obstacle crossing. Despite reporting significant effects to the verbal reaction task, they did not report data on obstacle clearance.

These results suggest that cognitive interference may influence obstacle crossing but the strength and nature of this influence is unclear. The difficulty in ascertaining the effect of cognitive performance on stepping control may be linked to the small critical period of obstacle crossing (~2s), that would allow uncompleted cognitive tasks to be temporarily suspended during obstacle crossing. It could also be due to insufficient cognitive demands used in some of these dual-task scenarios, since with increased attention demands dual-task interference on walking is typically observed [15-17].

Here we increase the likelihood of detecting genuine cognitive interference during obstacle crossing by increasing the duration of trials to record multiple steps and employ a continuous cognitive task. By maintaining the motor task over a longer duration it becomes possible to implement a concurrent cognitive task that is continuous. For this purpose we selected a word generation task that requires the continuous generation of novel words. Word generation tasks of this nature are cognitively demanding and have been shown to interfere with walking performance [17]. Critically, verbal fluency requires sustained attention to organise verbal output and to keep track of the words that have already been generated [18, 19] but it can be performed without the complication of visual distraction. We anticipate that the demands of sustaining attention on obstacle crossing whilst carrying out the verbal task will lead to observable changes in foot placement and/or cognitive performance. Since older adults have a natural decline in cognitive function [15] we predict that any observed interference effects would be greater with advanced age.

Methods

Participants

Forty-six community dwelling volunteers participated. Twenty-one were aged between 20-29 years (mean=20.23, SD=2.49 years), 13 were aged between 60-69 years (mean=64.77, SD=3.23 years), and 11 were aged between 70-79 years (mean=74.00, SD=3.23 years). Older adults were divided into two age groups following pilot work showing that cognitive interference on walking was greater for a group of adults aged 70-79 compared to a group aged 60-69. Inclusion criteria were the ability to walk for one minute without aid (e.g. walking stick/frame), normal or corrected to normal vision (e.g. glasses/contact lenses), and no cognitive impairment. All participants attained a Mini Mental State Examination [20] score>26, and a National Adult Reading Test [21] score>30. There were no significant differences in screening scores across the three age groups. These screening tests indicate that all adults included in the study were free from significant impairments to cognitive function, and that they attained comparable intellectual standards for reading ability. The University of Reading ethics and research committee approved the particulars of this study (Project 02/41, 22nd-January-2003) and all participants gave written informed consent prior to data collection in accordance with the Declaration of Helsinki.

Verbal fluency

Verbal fluency, the ability to produce novel and context appropriate responses to a given topic, is traditionally examined using a controlled oral word generation task. To complete this task, participants are given a target letter (e.g. F/A/S) and speak aloud as many words as possible that begin with that letter for one minute. Valid words include proper English words, or those common to the English language. Invalid words include plurals of the same word, repetitions, or nonsense words. In healthy adults, test-retest correlations of verbal fluency show reasonable reliability; r>.70 (Pearson product-moment correlation) for both short and long intervals [22, 23].

Apparatus

Participants walked along a 14.5metre figure-of-eight path. Their lower limbs were instrumented with eight spherical reflective body markers placed bilaterally on the following anatomical landmarks: distal end of first metatarsal, the head of the fifth metatarsal, calcaneus, and lateral epicondyle. Figure 1 illustrates the experimental set up. Two rectangular obstacles were placed near the centre of the track and participants stepped over them as they walked. The small obstacle measured 25x76x300mm, the large 152x76x300mm, with similar dimensions to obstacles used in previous research [24]. The top corners of each obstacle were marked with reflective tape so that they could be identified by the position-tracking camera system and placed in the 3D reconstructed world. Foot placements and trajectories over the obstacles were monitored by 4xVicon motion capture cameras (Oxford Metrics, UK), which tracked the reflective body and obstacle markers at a sampling frequency of 120Hz within 1.5mm error. A digital camera was positioned to record contact errors and verbal responses.

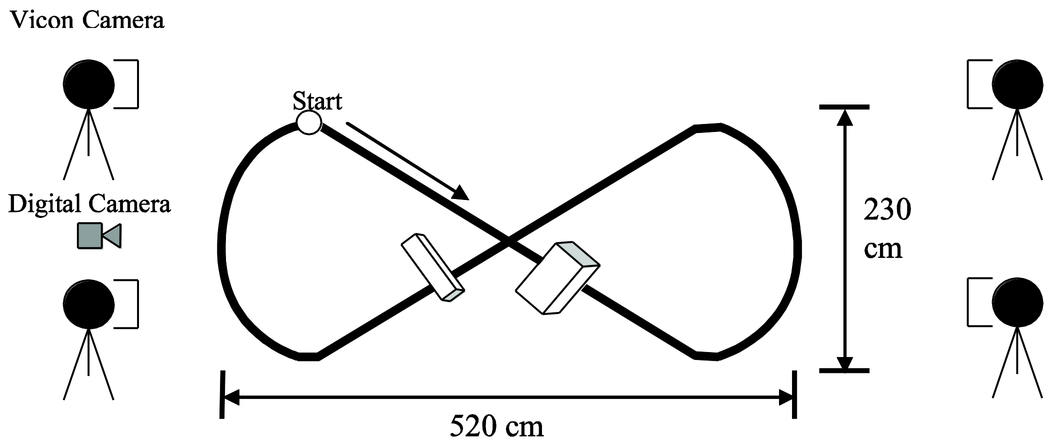

Figure 1. Figure-of-eight track and experimental set-up. Four Infra-red tracking cameras recorded the position of retro-reflective markers present in the scene. These were attached to the corners of the obstacles, as well as to key anatomical locations on the lower limbs. The diagram shows the relative location of equipment and obstacles, but the figure is not drawn to scale.

Protocol

Participants received standardised instructions to walk briskly around the track for 60 seconds, crossing the centre of the obstacles, whilst walking and generating new words until the trial ended. Participants completed three trials i) walking and obstacle crossing, concurrent with verbal fluency, ii) walking and obstacle crossing (no concurrent task) and iii) walking with obstacles removed, concurrent with verbal fluency. Each task was completed once but since participants walked continuously for one minute data was collected for multiple obstacle crossings. The average number of obstacle crossings per trial was 10.76 (20-29 group), 7.38 (60-69 group), and 7.88 (70-79 group).

Task iii) above determined participants' baseline (single-task) verbal fluency. Baseline verbal fluency was measured during walking rather than sitting or standing to account for the attentional demands of walking, which are greater than sitting or standing [9]. This allowed us to separate the attention demands of obstacle crossing from that of walking. For all verbal fluency trials, participants began to generate words as soon as they started walking. Practice trials were given with additional verbal stimuli and participants were encouraged to rest between trials. Task order was randomised and counterbalanced within and across age groups to reduce practice and fatigue effects.

Data collection and analysis

Conventional labelling of the limbs was used: the lead foot crossed the obstacle first; the trail foot crossed second. The Vicon system recorded spatio-temporal data of foot trajectories about the obstacles. From this data, we used the following measures: trail-toe distance, lead-heel distance, trail-toe clearance, lead-toe clearance, and step velocity. Lead and trail-toe clearance were calculated as the distance from the upper surface of the obstacle to the toe at crossing. Within-subject coefficient of variation [(individual SD/individual mean)x100] was calculated as a measure of individual 'inconsistency' or variability in obstacle crossing. Obstacle contacts did not provide sufficient data for analysis since there were only two collisions: one participant (20-29 group) contacted with the trail-toe prior to obstacle crossing and one participant (60-69 group) contacted with the lead toe during obstacle crossing. Performance of the verbal task was determined by the number of valid words generated during each 1-minute trial. Group means and standard errors for the measures given above are presented in Table 1.

Separate repeated measures analysis of variance (ANOVA) tests determined the effect of task (no verbal task, concurrent verbal task) and obstacle size (large obstacle, small obstacle) on each measurement of foot placement about the obstacles (trail-toe distance, lead-heel distance, trail-toe clearance, lead-toe clearance, horizontal velocity), with age group membership as a between subjects factor (20-29, 60-69, 70-79). Repeated measures ANOVAs were carried out on the within subject variability scores, for each measure of foot placement (as detailed above) comparing single to dual-tasks for each age group.

Table 1. Mean and standard error values for single and dual-task trials. Table shows values for absolute and within-subject variability of foot placement during obstacle crossing, as well as absolute obstacle crossing velocity, and verbal fluency, for each age group.

Age Group	20-29	60-69	70-79
Trail toe distance (mm)			
Single	228.97 (12.18)	219.78 (6.23)	211.56 (14.17)
Dual	218.78 (11.56)	193.24 (11.29)	217.81 (18.01)
Within-subject variability†			
Single	37.15 (2.61)	27.86 (2.36)	20.10 (2.46)
Dual	26.94 (1.60)	22.30 (2.51)	25.99 (4.32)
Lead heel distance (mm)			
Single	221.08 (14.20)	134.69 (9.15)	117.89 (11.69)
Dual	204.58 (11.33)	131.36 (10.71)	121.71 (12.62)
Within-subject variability†			
Single	29.31 (1.98)	32.45 (4.12)	31.97 (3.44)
Dual	27.56 (2.31)	27.18 (3.98)	45.98 (8.20)
Lead toe clearance (mm)			
Single	141.28 (6.12)	149.52 (10.08)	158.50 (5.47)
Dual	152.57 (7.52)	159.72 (11.42)	160.24 (6.02)
Within-subject variability†			
Single	42.13 (1.37)	38.51 (1.22)	34.96 (0.99)
Dual	38.08 (1.21)	37.34 (2.18)	34.31 (2.38)
Trail toe clearance (mm)			
Single	136.62 (12.09)	123.23 (11.96)	155.82 (8.88)
Dual	145.21 (12.71)	133.77 (11.47)	132.83 (14.94)
Within-subject variability†			
Single	48.48 (1.42)	40.62 (2.07)	36.71 (2.50)
Dual	46.76 (1.42)	43.68 (2.54)	40.82 (2.94)
Step velocity (m/sec)			
Single	0.47 (0.01)	0.43 (0.01)	0.38 (0.01)
Dual	0.45 (0.01)	0.40 (0.01)	0.35 (0.01)
Word Generation ‡			
Single	15.00 (1.37)	18.15 (1.54)	17.82 (2.45)
Dual	12.68 (0.81)	15.77 (1.42)	18.27 (2.44)

Data presented are group means and data in parenthesis are standard error (SE) values. †Within-subject variability values are calculated as within-subject coefficient of variance ((individual SD/individual mean)x100).

‡Word Generation is calculated as the number of valid words spoken during the 60 second trial.

A repeated measures ANOVA examined the effect of walking with and without obstacles on the number of valid words generated, with age group as a between subjects factor. For all analyses, post-hoc tests examined the direction and nature of group differences. For each post-hoc analysis an ordered Bonferroni procedure [25] adjusted the alpha level to correct for multiple contrasts (ensuring the overall 'experiment wise' alpha remained equivalent to 0.05 during repeated testing).

Results

Foot placement, trajectory, and variability of step approach

Whilst there was no experimental effect on absolute trail-toe distance there was a main effect of age on the variability of trail-toe distance, $F(2, 42)=6.93$, $p=.003$, $\eta^2=.25$. This showed that the 20-29 group had a more variable single-task trail-foot position than the older adults. However, an interaction between age and cognitive task ($F(2, 42)=4.45$, $p=.018$, $\eta^2=.18$) showed that the addition of the verbal task led to decreased variability in trail-toe distance for the 20-29 and 60-69 groups but increased variability for the 70-79 group (Figure 2a).

Foot placement, trajectory, and variability of step crossing

There was a main effect of age, $F(2, 42)=20.10$, $p<.001$, $\eta^2=.49$, showing the 70-79 group landed closer to the far edge of the obstacles (lead-heel distance) than the 20-29 ($p=.019$) and 60-69 ($p=.033$) groups. An interaction between age and cognitive task is shown in Figure 2b for the variability of lead-heel positioning, $F(2, 42)=4.20$, $p=.022$, $\eta^2=.17$; the addition of the verbal task led to increased variability of lead-heel positioning for the 70-79 group but not for the other age groups.

There was no main effect of age on trail-toe clearance, but there was an age and task interaction ($F(2, 42)=4.79$, $p=.013$, $\eta^2=.19$). This showed that carrying out the verbal task led to increased trail-toe clearance in the 60-69 and 20-29 groups but decreased trail-toe clearance in the 70-79 groups (Figure 2c). The addition of the verbal task led to increased lead-toe clearance, $F(1, 42)=5.86$, $p=.020$, $\eta^2=.12$ (Figure 2d). There were no experimental effects on the variability of trail-toe or lead-toe clearance. Obstacle clearance was greater for the large obstacle compared to the small for both trail-toe ($F(1, 42)=46.41$, $p<.001$, $\eta^2=.49$) and lead-toe ($F(1, 42)=91.32$, $p<.001$, $\eta^2=.67$) measures.

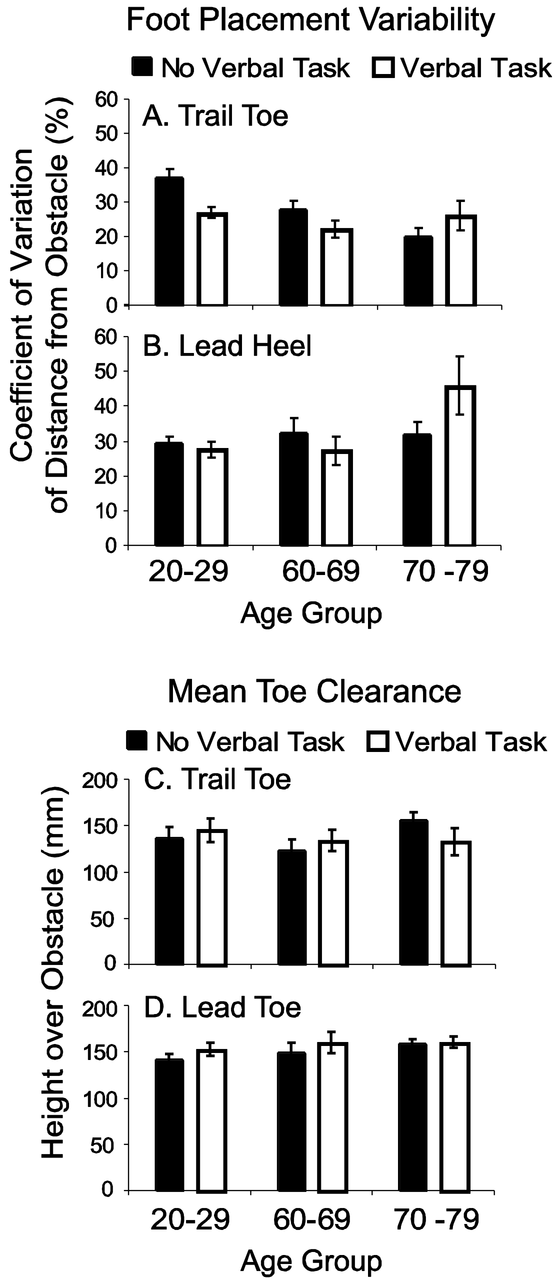

Figure 2. Obstacle crossing. White bars show single-tasks (stepping with no verbal fluency) and black bars show dual tasks (stepping concurrent with verbal fluency), for each age group (20-29, 60-69, 70-79). Four measures of obstacle crossing are shown: **A**. Within-subject variability (within-subject coefficient of variation) in trail-toe distance; **B**. Within-subject variability (within-subject coefficient of variation) in lead-heel distance; **C**. Trail-toe clearance (mm); and **D**. Lead-toe clearance (mm). For all graphs data are averaged across high and low obstacles, and the bars show +/- standard error of the mean for each group.

Velocity of stepping

There was a main effect of age on obstacle crossing velocity ($F(2, 42)=24.49$, $p<.001$, $\eta^2=.538$); the 20-29 group crossed faster than the 60-69 ($p=.003$) and 70-79 ($p<.001$) groups and the 60-69 group crossed faster than the 70-79 group ($p=.007$). Crossing velocity was reduced during dual-task compared to single-task trials, $F(1, 42)=24.52$, $p<.001$, $\eta^2=.37$, and was reduced when crossing the larger obstacle compared to the smaller obstacle, $F(1, 42)=10.68$, $p=.002$, $\eta^2=.19$.

Verbal fluency

There was no main effect of age or task on verbal fluency. However an age by task interaction showed the 70-79 group generated more words than the 20-29 group during obstacle crossing trials, $F(2, 43)=4.13$, $p=.023$, $\eta^2=.16$, but not during walking only trials (Figure 3). Fewer words were generated during obstacle crossing trials compared to no-obstacle walking $F(1, 42)=4.44$, $p=.041$, $\eta^2=.09$, but this was only significant for the 20-29 group ($p=.014$).

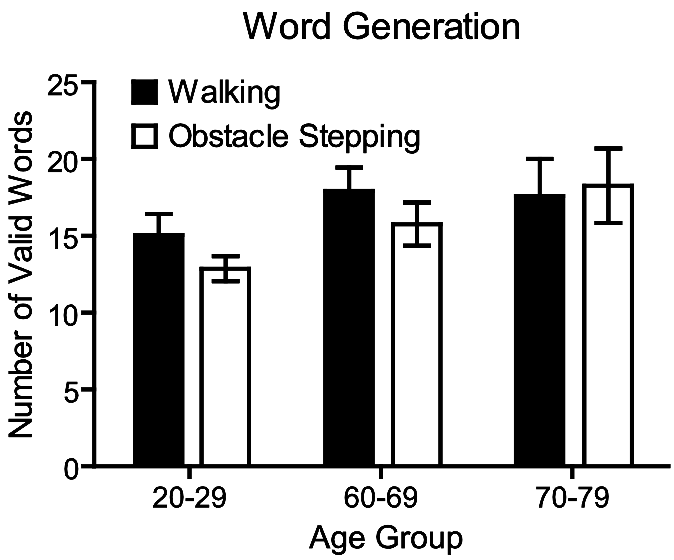

Figure 3. Word Generation. Black bars show the average number of valid words generated by each age group (20-29, 60-69, 70-79). Black bars represent single-task trials (verbal fluency during walking with no obstacle crossing) and white bars represent dual-task trials (verbal fluency during walking with obstacle crossing). The data presented are averaged across high and low obstacles, and the bars show +/- standard error of the mean.

Discussion

This study demonstrated that concurrent cognitive-verbal activity affected obstacle crossing of each age group in a different way. Perhaps surprisingly, whilst both older groups showed similar obstacle crossing behaviour during single-task trials, the 60-69 group showed similar changes to obstacle crossing as the 20-29 group during dual-task trials. For example, both the 20-29 and 60-69 groups employed a ‘posture-protective’ strategy by reducing step velocity and increasing trail and lead-toe clearance as task demands increased. This modified gait in a way that reduced the risk of foot contact during obstacle crossing. As well as modifying gait with more conservative obstacle crossing strategies, both 20-29 and 60-69 groups showed small reductions to verbal output during dual-task trials. It is possible that this small reduction in verbal performance allowed sufficient attentional resources to be available for these posture-preserving changes, in line with similar observations of dual-task interference during complex motor tasks [26].

The 70-79 group crossed the obstacles safely and were in some instances the most conservative of the three groups, especially during single-task trials. However, unlike the younger groups, they did not consistently behave in a manner that suggested posture-preservation as task demands increased. The 70-79 group showed some signs of preserving stepping control during dual-task trials, such as increased lead-toe clearance and reduced velocity. Conversely, they also reduced trail-toe clearance and had increased variability of trail and lead-foot landing distances. Interestingly the 70-79 group had increased lead-toe clearance (the same as the other age groups) but decreased trail-toe clearance under dual-task conditions. Lead-foot placement is controlled and modified using online visual information and the preservation of posture in this phase suggests that attention demands were moderate. For the trail-foot to cross the obstacle, visual information may still be used, but in a feed-forward manner in conjunction with online kinaesthetic sensory feedback [27]. The decreased trail-toe clearance in the oldest group of adults implies that this stage of obstacle crossing may require greater demands on cognitive resources than earlier stages. The 70-79 group also maintained verbal output between single and dual-task trials, providing tentative evidence that cognitive resources may have been misallocated towards maintaining cognitive activity in this group.

The results of our study raise important issues regarding the interpretation of postural outcomes during dual-tasks. Interpretation of whether performance is improved or impaired may be difficult for some postural measures. For example, several studies have reported that carrying out a cognitively demanding task can lead to a reduction in postural sway during upright standing, especially for older adults [11, 28]. One interpretation of this is that increased cognitive activity improves postural control as it removes overt attention from an 'overly automised' postural activity [4]. A contrasting suggestion is that a dual-task reduction in postural sway could be due to individuals co-contracting the muscles supporting the ankles [10, 11], serving to stiffen the lower limbs. A reduction in sway may therefore be a posture-protective mechanism in response to competing demands on attention resources, which is more likely to be exhibited by older adults who are experiencing greater attentional conflict than younger adults. As with postural sway, increased obstacle clearance could be interpreted as either improved postural control or a conservative posture-protective strategy. In the present study, we would suggest that the 70-79 group were stepping more conservatively than the younger adults during single-task trials but increased attentional demands during dual-task trials led to a failure of this posture-protective strategy. For the younger groups the single-task trials were not sufficiently demanding to warrant a posture protective strategy, but increased attention demands during dual-task trials saw the use of posture-protective strategies in the two younger groups. We would therefore predict that as attention demands increased further that the 70-79 group would show greater reductions in obstacle crossing performance (a further decrease in obstacle clearance or increased variability). We would also predict that with further increases in attention demands that the 60-69 and subsequently the 20-29 would show similar reductions in obstacle crossing performance as the 70-79 group.

The results of this study extend the general dual-task posture control literature to encompass multiple obstacle-crossing whilst walking. We have shown that concurrent cognitive activity affects obstacle crossing differently in adults of different ages, but the relationship between cognitive activity, postural control, and age is complex. We have provided some evidence that individuals may utilise a 'posture-protective' strategy to safeguard obstacle crossing when attention demands increase. The use of this preservation strategy, however, appears to be used less consistently with advanced age. It could be that with advanced age there is a general failure to prioritise cognitive resources to important tasks [26], or that switching cognitive resources between tasks becomes more difficult. Further research is required that reliably manipulates attention demands during obstacle crossing (to include low, moderate, and high demands) for young and older adults. Only with these manipulations would it be possible to fully understand the complex relationship between obstacle crossing, advanced age, and attention demands.

References

[1] Hayes WC, Myers ER, Robinovitch SN, Van Den Kroonenberg A, Courtney AC, McMahon TA. Etiology and prevention of age-related hip fractures. Bone 1996;18(1 Suppl)**:** 77S-86S.

[2] Campbell AJ, Borrie MJ, Spears GF, Jackson SL, Brown JS, Fitzgerald JL. Circumstances and consequences of falls experienced by a community population 70 years and over during a prospective study. Age Ageing 1990;19(2)**:** 136-41.

[3] Woollacott M, Shumway-Cook A. Attention and the control of posture and gait: a review of an emerging area of research. Gait Posture 2002;16(1)**:** 1-14.

[4] Huxhold O, Li SC, Schmiedek F, Lindenberger U. Dual-tasking postural control: aging and the effects of cognitive demand in conjunction with focus of attention. Brain Res Bull 2006;69(3)**:** 294-305.

[5] Lindenberger U, Marsiske M, Baltes PB. Memorizing while walking: increase in dual-task costs from young adulthood to old age. Psychol Aging 2000;15(3)**:** 417-36.

[6] Frank JS, Patla AE. Balance and mobility challenges in older adults: implications for preserving community mobility. Am J Prev Med 2003;25(3 Suppl 2)**:** 157-63.

[7] Shumway-Cook A, Patla A, Stewart A, Ferrucci L, Ciol MA, Guralnik JM. Environmental components of mobility disability in community-living older persons. J Am Geriatr Soc 2003;51(3)**:** 393-8.

[8] Shumway-Cook A, Patla AE, Stewart A, Ferrucci L, Ciol MA, Guralnik JM. Environmental demands associated with community mobility in older adults with and without mobility disabilities. Phys Ther 2002;82(7)**:** 670-81.

[9] Lajoie Y, Teasdale N, Bard C, Fleury M. Attentional demands for static and dynamic equilibrium. Exp Brain Res 1993;97(1)**:** 139-44.

[10] Benjuya N, Melzer I, Kaplanski J. Aging-induced shifts from a reliance on sensory input to muscle cocontraction during balanced standing. J Gerontol A Biol Sci Med Sci 2004;59(2)**:** 166-71.

[11] Melzer I, Benjuya N, Kaplanski J. Age-related changes of postural control: effect of cognitive tasks. Gerontology 2001;47(4)**:** 189-94.

[12] Schrodt LA, Mercer VS, Giuliani CA, Hartman M. Characteristics of stepping over an obstacle in community dwelling older adults under dual-task conditions. Gait Posture 2004;19(3)**:** 279-87.

[13] Chen HC, Schultz AB, Ashton-Miller JA, Giordani B, Alexander NB, Guire KE. Stepping over obstacles: dividing attention impairs performance of old more than young adults. J Gerontol A Biol Sci Med Sci 1996;51(3)**:** M116-22.

[14] Brown LA, McKenzie NC, Doan JB. Age-dependent differences in the attentional demands of obstacle negotiation. J Gerontol A Biol Sci Med Sci 2005;60(7)**:** 924-7.

[15] Royall DR, Lauterbach EC, Cummings JL, Reeve A, Rummans TA, Kaufer DI, LaFrance WC, Jr., Coffey CE. Executive control function: a review of its promise

and challenges for clinical research. A report from the Committee on Research of the American Neuropsychiatric Association. J Neuropsychiatry Clin Neurosci 2002;14(4)**:** 377-405.

[16] Coppin AK, Shumway-Cook A, Saczynski JS, Patel KV, Ble A, Ferrucci L, Guralnik JM. Association of executive function and performance of dual-task physical tests among older adults: analyses from the InChianti study. Age Ageing 2006;35(6)**:** 619-24.

[17] Cockburn J, Haggard P, Cock J, Fordham C. Changing patterns of cognitive-motor interference (CMI) over time during recovery from stroke. Clin Rehabil 2003;17(2)**:** 167-73.

[18] Parker DM, Crawford JR, *Assessment of frontal lobe dysfunction.*, in *Handbook of Neuropsychological Assessment*, J.R. Crawford, W. McKinlay, and D.M. Parker, Editors. 1992, Erlbaum and Associates: Hove. p. 267-291.

[19] Estes WK. Learning theory and intelligence. Am Psychol 1974;29(740-749.

[20] Folstein MF, Folstein SE, McHugh PR. "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res 1975;12(3)**:** 189-98.

[21] Nelson HE, Willison JR, *National Adult Reading Test Manual*. Second ed. 1991, Windsor, UK: NFER - Nelson.

[22] Tombaugh TN, Kozak J, Rees L. Normative data stratified by age and education for two measures of verbal fluency: FAS and animal naming. Arch Clin Neuropsychol 1999;14(2)**:** 167-77.

[23] Dikmen SS, Heaton RK, Grant I, Temkin NR. Test-retest reliability and practice effects of expanded Halstead-Reitan Neuropsychological Test Battery. J Int Neuropsychol Soc 1999;5(4)**:** 346-56.

[24] Chen HC, Ashton-Miller JA, Alexander NB, Schultz AB. Stepping over obstacles: gait patterns of healthy young and old adults. J Gerontol 1991;46(6)**:** M196-203.

[25] Bonferroni CE. Teoria statistica delle classi e calcolo delle probabilit `a. Pubblicazioni del R Istituto Superiore di Scienze Economiche e Commerciali di Firenze 1936;8(3-62.

[26] Bloem BR, Valkenburg VV, Slabbekoorn M, Willemsen MD. The Multiple Tasks Test: development and normal strategies. Gait Posture 2001;14(3)**:** 191-202.

[27] Mohagheghi AA, Moraes R, Patla AE. The effects of distant and on-line visual information on the control of approach phase and step over an obstacle during locomotion. Exp Brain Res 2004;155(4)**:** 459-68.

[28] Swan L, Otani H, Loubert PV, Sheffert SM, Dunbar GL. Improving balance by performing a secondary cognitive task. Br J Psychol 2004;95(Pt 1)**:** 31-40.