

# Influences of State Anxiety on Gaze Behavior and Stepping Accuracy in Older Adults During Adaptive Locomotion

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**Objectives.** Older adults deemed to be at a high risk of falling transfer their gaze from a stepping target earlier than their low-risk counterparts. The extent of premature gaze transfer increases with task complexity and is associated with a decline in stepping accuracy. This study tests the hypothesis that increased anxiety about upcoming obstacles is associated with (a) premature transfers of gaze toward obstacles (i.e., looking away from a target box prior to completing the step on it in order to fixate future constraints in the walkway) and (b) reduced stepping accuracy on the target in older adults.

**Methods.** High-risk (9) and low-risk (8) older adult participants walked a 10-m pathway containing a stepping target area followed by various arrangements of obstacles, which varied with each trial. Anxiety, eye movements, and movement kinematics were measured.

**Results.** Progressively increasing task complexity resulted in associated statistically significant increases in measures of anxiety, extent of early gaze transfer, and stepping inaccuracies in the high-risk group.

**Discussion.** These results provide evidence that increased anxiety about environmental hazards is related to suboptimal visual sampling behavior which, in turn, negatively influences stepping performance, potentially contributing to increased falls risk in older adults.

**Key Words:** Anxiety—Attention—Locomotion—Older adults—Vision.

AS we move through our cluttered world, we generate eye movements in order to fixate aspects of our environment and gather useful visual information necessary to negotiate constraints in our path. This process, known as visual sampling (Patla, 1991), is affected by the aging process producing measurable differences in looking (gaze) behavior (Chapman & Hollands, 2006, 2007). For example, older adults tend to look at stepping constraints (e.g., obstacles or stepping targets) earlier than, and for longer than, younger adults prior to stepping on or over them (Chapman & Hollands, 2006, 2007; Di Fabio, Zampieri, & Greany, 2003). There are also differences between older adults deemed to be at a high or low risk of falling in the timing of gaze shifts away from stepping targets. Chapman and Hollands (2006, 2007) found that high-risk older adults (HROA) transferred gaze away from a stepping target significantly earlier than low-risk older adults (LROA) during the ongoing swing phase of the targeting limb. The extent of early gaze transfers was found to increase in line with the number of stepping constraints following the target. Furthermore, the extent of early gaze transfer appears to correlate with measures of decline in stepping performance (Chapman & Hollands, 2007). Previous work from our laboratory has shown evidence for a causal link within this relationship, as when instructed to delay gaze transfer from a target (until

after the foot had landed inside it), older adults demonstrated overall improvements in stepping accuracy and a reduction in variability of stepping error (Young & Hollands, 2010).

In the above studies, gaze transfer from a stepping target allowed fixation of a future constraint in the travel path. Therefore, premature gaze transfer could be interpreted to be a result of inappropriate prioritization of sampling of visual cues relating to future constraints over visual cues relating to the ongoing stepping action. The question remains: why do HROA adopt this apparently maladaptive visual sampling strategy?

One possible mediator of the altered visual sampling behavior shown by HROA is anxiety relating to the presence of upcoming obstacles and other environmental features posing a threat to stability. An increased perception of postural threat has been repeatedly shown to influence various components of balance control, provoking conservative adaptations such as increased co-contraction of agonist and antagonist muscles controlling ankle flexion and extension (Carpenter, Frank, & Silcher, 1999), resulting in reduced variability and increased frequency of postural sway (Adkin, Frank, Carpenter, & Peysar, 2000). Furthermore, an increased fear of falling impairs performance in postural sway tasks (Maki, Holliday, & Topper, 1991) in a manner that cannot be explained by muscle weakness (Binda, Culham, & Brouwer, 2003). More recently, studies have revealed

that perceptions of increased postural threat and anxiety are associated with reduced performance in balance tasks such as standing on one leg (Hauck, Carpenter, & Frank, 2008) and alterations in gait parameters such as a reduction in gait speed, stride length, and stride frequency (Chamberlin, Fulwider, Sanders, & Medeiros, 2005; Reelick, van Iersel, Kessels, & Rikkert, 2009). However, anxiety-related adaptations to gait serve to reduce the risk of gross stepping errors in older adults and therefore may be beneficial in certain situations requiring obstacle avoidance (Brown, Polych, & Doan, 2006).

Gage, Sleik, Polych, McKenzie, and Brown (2003) provided evidence that increased anxiety alters the allocation of attention during gait under dual task conditions. Moreover, in a cognitive paradigm Lee and Knight (2009) reported that older adults with high trait anxiety generally directed attention to words with negative connotations. Heightened anxiety, therefore, is instrumental in promoting attentional biases toward factors that are perceived as most threatening (Folk, Remington, & Johnston, 1992). Consequently, when required to negotiate multiple constraints in a travel path, increased anxiety levels regarding a future walking constraint may drive earlier transfer of visual fixation toward it.

To date, none of the aforementioned studies has described gaze behavior in older adults prior to final fixation and arrival at a series of stepping constraints. That is, we have no information about the frequency with which, and the extent to which, participants look ahead to gain information describing target characteristics. It would be relevant to know, for example, whether older adults who transfer gaze away earlier from a target spent less time previewing the target during the approach to it. The overall goal of the current study is to provide this missing information.

The specific aims of the current experiment are to (a) determine the extent to which HROA's gaze behavior and associated decline in stepping accuracy are associated with increased levels of state anxiety and (b) compare the visual sampling characteristics of HROA and LROA during the approach with stepping targets and determine how these relate to gaze behavior during target negotiation. We hypothesize that there are fall risk-related differences in visual sampling behavior during both the approach to, and stepping onto, targets and that altered gaze behavior is associated with increased anxiety about future stepping constraints in the travel path. We further hypothesize that HROA will show progressively higher levels of anxiety as the complexity of the stepping task is increased and that levels of anxiety will correlate with early gaze transfer away from the target and associated decline in stepping precision.

## METHOD

### Participants

Seventeen healthy community-dwelling older adults were recruited from local community centers and sheltered

accommodation establishments to participate in the study (eight LROA and nine HROA). Participants were excluded from participation if diagnosed with any musculoskeletal or neurological impairment or if prescribed medication for dizziness or anxiety. Participants requiring the use of eyeglasses for daily locomotor activities were also excluded due to incompatibility with the gaze tracking equipment detailed below (one LROA and one HROA used contact lenses on a regular basis and throughout the study). Of all candidates willing to take part in the study, approximately 50% were eligible to participate. Participants underwent a battery of psychophysiological and visual tests prior to entering the laboratory. Individuals who had experienced a fall in the previous twelve months were deemed to be a HROA if their Berg Balance Score was lower than 45/56 (Berg, Alessio, Mills, & Tong, 1997). A Berg Balance Score of 45/56 is an established criterion for identifying community-dwelling older adults at risk of falling (Lajoie & Gallagher, 2004; Riddle & Stratford, 1999). One participant achieved a Berg Balance Score of 53/56 and reported having fallen once (slipped on ice without injury) nine months previous to participation in the study. Although Nevitt, Cummings, Kidd, and Black (1989) showed that two from every three older adults who experience a fall will fall again in the following twelve months, this participant was deemed an LROA due to the high Berg Balance Score and the isolated nature of the fall. The experimental protocol was approved by The University of Birmingham Ethics Committee and was carried out as an independent study in the Kinesiology Laboratory at The University of Birmingham, United Kingdom, in accordance with the principles laid down by the Declaration of Helsinki. All participants provided written informed consent prior to participation.

### Measures

Binocular contrast sensitivity (the ability to distinguish details at low contrast levels) was assessed using the Pelli–Robson letter sensitivity test (Pelli–Robson contrast sensitivity chart 4K; Metropia Ltd, UK) at a distance of 1 m. Scores were calculated according to the number of correct letters read and converted to a log contrast sensitivity, where a score of 2 represents 100% sensitivity and a score of 1 represents a disability in detecting contrasts (Pelli, Robson, & Wilkins, 1988). Using a Snellen eye chart, we found that no participants had significant deficits in visual acuity, as all demonstrated 20/40 vision or better in both eyes. Lower peripheral vision was measured by kinetic perimetry using a Goldman perimeter with a V/4e target (1.75° test spot at 320 cd/m<sup>2</sup>) on a backing luminance of 10 cd/m<sup>2</sup>. We measured the extent of the lower peripheral field (the maximum vertical angle below the line of gaze held horizontally and vertically at 0°). This angle was measured at three positions along an arc extending ±5° from center (0°) of the horizontal plane. The mean score was calculated from all three horizontal

Table 1. Participant Characteristics

Measure	Low risk	High risk	<i>t</i>
Age (years)	72.88 (67–82)	75.67 (68–83)	
Berg Balance Scale	54.83 (54–56)	45.89 (44–48)	14.5*
Participant's previously fallen <sup>a</sup>	1/8	7/9	
Pelli–Robson (contrast sensitivity)	1.71 (1.5–1.95)	1.58 (1.05–1.8)	
Lower 10° peripheral vision	73.37 (60.3–81.3)	73.45 (65.3–80)	
Activities Balance Confidence Scale	90.84 (69.9–98.88)	82.59 (61.65–97)	
Spielberger's state anxiety	29 (20–37)	33.89 (28–42)	
Spielberger's trait anxiety	28.13 (21–38)	28.89 (23–41)	

Notes. <sup>a</sup>Number of participants who reported falling once or more in the previous twelve months.

\**p* < .05.

positions and from both eyes. We found that all participants had a lower visual field of over 60° and therefore had no deficits in this measure (Zadnik, 1997). Collectively, these results confirm that all participants had no significant visual disabilities. One-way analysis of variance (ANOVA) also revealed that there were no significant differences between groups in any of the visual tests described (see Table 1).

Cognitive functioning of all participants was examined using the Mini-Mental State questionnaire (Folstein, Folstein, & McHugh, 1975). All participants achieved a score of >26, indicating no major deficits in cognitive functioning. Participants completed the Activities Balance Confidence Scale (Powell & Myers, 1995) where responses of 67% or less represent a significant loss of confidence in the ability to perform everyday tasks without falling. State and trait anxiety were assessed at the start of each session (prior to the start of the walking tasks) using Spielberger's State-Trait Anxiety Inventory (STAI; Spielberger, 1975). STAI is a 40-item self-reported inventory that distinguishes between dispositional (trait) and transitory (state) anxiety. Scores range from 20 to 80, higher scores indicating increased anxiety, with scores over 40 indicating clinically significant anxiety-related symptoms (Forsberg & Björwell, 1993). A one-way ANOVA revealed no between-group differences in perceptions of balance confidence, trait, or state anxiety at the time immediately before the start of the session (see Table 1).

During the course of the study, further measures of state anxiety were taken using a short self-reported anxiety (SRA) inventory modified from Spielberger (1975). Retrospective self-reported inventories have been used in previous studies to provide an assessment of state anxiety in the context of balance-related tasks (Carpenter, Adkin, Brawley, & Frank, 2006; Hauck et al., 2008). Several studies have also taken measures of electrodermal response (EDR) as an indication of physiological arousal (Gage et al., 2003; Hauck et al., 2008; Rosengren & McAuley, 1998) and found that fluctuations in such measures vary according to the context and difficulty of the task (Rosengren & McAuley, 1998). We included EDR measures in the current study

to provide an examination of physiological arousal within each of the experimental conditions.

### Data Collection

Wearing flat-soled shoes, participants were fitted with reflective markers placed equidistantly between the head of the distal interphalangeal joints of the first and fifth metatarsals (toe marker), on the most posterior point of the heel, and on both medial and lateral sides (mid-foot markers) of the shoe.

Each marker was sampled at 120 Hz using a Vicon MX motion analysis system (Oxford Metrics, England). Spatial and temporal components of gaze behavior were measured using a high-speed ASL 500 head-mounted gaze tracking system, whereby both vertical and horizontal components of eye movements were synchronized and recorded with the Vicon video data at 120 Hz via two analogue inputs (vertical and horizontal) produced by the ASL controller. The ASL controller also produced a digital video image (30 Hz) displaying the visual scene of each participant, with a superimposed cursor representing the area of gaze fixation. This video was used to assess the environmental features fixated by each participant during each trial. EDR was measured using a Biopac mp150 and AcqKnowledge 3.8.1 software, with electrodes attached to digits 2 and 3. SRA measures were taken using a modified (task specific) version of Spielberger's state anxiety inventory (Spielberger, 1975). Each questionnaire comprised four task-specific questions: (a) I feel calm when completing the task, (b) I feel tense when stepping into the box, (c) I feel relaxed when stepping into the box, and (d) I am worried that I may lose my balance. Anxiety responses were scaled 0–3 (0 = *not at all*, 1 = *somewhat*, 2 = *moderately*, and 3 = *very much*). Participants were instructed to answer with respect to how they felt during their approach until the step into the target was complete.

### Protocol

Similar techniques to those described below have been used previously by Chapman and Hollands (2006, 2007) and Young and Hollands (2010). Participants were instructed to walk along a 10-m travel path at their own pace and place their right foot into a stepping target. There were four experimental conditions determining the constraints that followed the stepping target: no further constraints (target only), one near obstacle (near obstacle), one far obstacle (far obstacle), and both near and far obstacles (both obstacles; see Figure 1). Participants were instructed to step over each obstacle (if present) using their right foot in each instance. There were 10 trials in each condition. Within each condition the stepping target was presented in one of two possible positions separated by 12 cm (mediolateral) and 8 cm (anterior–posterior). This was intended to reduce the degree of task predictability throughout the session. Equal

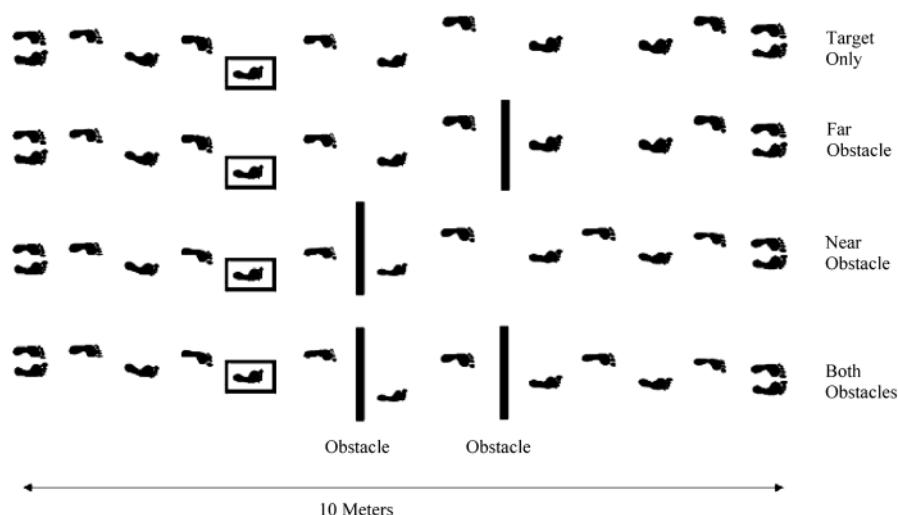


Figure 1. Schematic diagram of experimental task.

numbers of trials using each target position were presented within each condition, the order of which was randomized. Participants were required to complete two practice trials in each condition prior to the start of the first of the randomized trials.

Targets were made from firm lightweight packaging foam and were not secured to the floor. Inside each target was a rectangular stepping area measuring  $190 \times 415$  mm. The height and width of the target box frame measured  $40 \times 40$  mm. Participants were instructed to place their foot into the center of the box, leaving as much space as possible between the outside of the foot and the inside of the target box. Obstacles were made from plywood and designed to fall over with ease in the direction of walking should the foot of the subject come in to contact with it. Each obstacle was 22 cm high, 100 cm wide, and 1 cm thick. The near and far obstacles (if present) were placed on the walkway 100 and 180 cm following the anterior edge of the most anterior stepping target position.

Three-minute rest periods were given after every five trials, during which participants were required to sit and rest, allowing the EDR signal to return as close as possible to baseline levels. SRA inventories (one for each task condition) were retrospectively completed by each participant at the start of the rest period after 5, 20, and 40 trials. Two baseline EDR measurements were taken during each session: “Sat quietly” and “Normal walking.” Sat quietly measures were taken for four separate 8-s periods (two measurements prior to the start of the walking tasks and two after the 40 experimental trials). Each measurement was taken when the participant had been seated for 2 min. In addition, four EDR measures were taken under conditions of normal walking, two prior to the first and two following the last experimental trial. The mean EDR amplitude was recorded between the initiation of the first step and the heel contact nearest to the position where the stepping target would have been during experimental trials.

At the start of each trial, participants were requested to stand with their eyes closed (with the option to hold a rail) until given the verbal instruction: Open eyes. This was intended to limit the amount of attention directed toward the constraints in the walkway prior to the start of each trial. Participants started walking after receiving the verbal instruction: Go.

#### Data Analysis

Kinematic data were low-pass filtered with a cutoff frequency set at 5 Hz. Heel contact and toe off events were defined using an algorithm adapted from Hreljac and Marshall (2000). Toe off was determined as the minimum in vertical displacement of the toe marker, identified by zero crossings in the vertical velocity profile. Heel contact was determined as the maximum vertical acceleration of the heel marker, identified by zero crossing in the jerk profile (see Sorensen, Hollands, & Patla, 2002). Periods of “stance” were defined as the duration between a heel contact and the following toe off in the same foot. Periods of “swing” were defined as the duration between toe off and the following heel contact in the same foot. The area of gaze fixation was assessed using a frame-by-frame analysis of the digital scene video juxtaposed with the vertical and horizontal components of the gaze analogue signal. Saccade onset was defined as a local peak in eye acceleration with an amplitude greater than 5,000 degrees per second squared and which was coincident with an instantaneous eye velocity of less than 100 degrees per second. Saccade offset was defined as a local minimum in eye acceleration, occurring no later than 200 ms after a saccade onset, with an amplitude less than  $-5,000$  degrees per second squared and which was coincident with an instantaneous eye velocity of less than 100 degrees per second.

Gaze fixations were defined as being a gaze stabilization on a single environmental feature for 100 ms or longer



(Patla & Vickers, 1997). We then calculated the respective latencies between eye movements (onsets and offsets) and stepping events (heel contacts and toe offs). The time of gaze transfer from the target with respect to heel contact inside it was calculated by subtracting the time of saccade onset away from the target from the time of heel contact on the target. The duration of gaze fixation on any target or obstacle was calculated as the time period between the end of a saccade made to a particular target and the start of the next saccade away from the target.

The measurement of foot placement variability was assessed by taking the standard deviation of foot placement error on the target (the distance between the center of foot and the center of the target) from all trials completed in each experimental condition. The center of the foot was defined as the mid-point between the heel and toe markers. A “missed step” was defined as a step during which the foot of the participant contacted the boundaries of the stepping target. For each participant, the number of missed steps was represented as a percentage of the number of missed steps from the total number of trials completed in each condition. Walking velocity was determined by calculating the distance between the anterior–posterior displacement of the left toe marker at gait initiation and at heel contact (following the step into the target) and dividing by the time interval between these events.

For each experimental trial, we took the mean of the EDR signal that was recorded between the points of toe off to initiate gait at the start of each trial and heel contact on the target. The magnitude of this signal was expressed as a percentage of the difference between the two baselines (sat quietly and normal walking). Any percentage changes were plotted against that of walking at a self-selected pace with no constraints to give a measure of how the signal changed during experimental trials compared with normal walking.

A mixed design ANOVA was used to identify main effects and interactions of within-subject (four experimental conditions) and between-subject (two group) factors. The dependent variables assessed were (a) time interval between the onset of gaze transfer from the target and heel contact inside it, (b) the number of individual fixations on the target prior to heel contact inside it, (c) total fixation duration on the target box between the time of gait initiation and moment of heel contact on the target, (d) the number of individual gaze transfers from the target to either obstacle between the time of gait initiation and moment of heel contact on the target, (e) the percentage of missed steps, (f) foot placement variability in both mediolateral and anterior–posterior direction, (g) SRA level, and (h) EDR response. In order to assess the extent to which gaze and stepping behavior is influenced by anxiety, 2 one way between groups analyses of covariance (ANCOVA) were conducted on the following variables: the time of gaze transfer from the target relative to heel contact and the number of missed steps. In both ANCOVA, SRA values were included as a covariate.

As alterations in anxiety as well as visual and stepping behaviors are likely to be most pronounced during the most complex task, data were only included from the experimental condition containing the target and both obstacles. The covariate analysis was included to determine if any between-group effects in timing of gaze transfer and stepping accuracy are independent of anxiety measures and to allow a clearer interpretation of how much the variation in gaze and stepping behavior can be explained by measures of anxiety.

Nonparametric correlations (Spearman’s rank correlation coefficient) were used when analyzing SRA measures. Parametric correlation analysis (Pearson’s Product Moment Correlation Coefficient) was used for all other data sets. Each data point included in correlation analysis represented the mean value for each participant for one experimental condition (mean of 10 trials). Post hoc analysis was carried out using ANOVA. All significance levels were set a priori at  $p < .05$ .

## RESULTS

### Gaze Behavior

There was a significant interaction between group and condition for the time interval between gaze transfer away from the stepping target and heel contact on it. As demonstrated in Figure 2, the results show that compared with LROA, HROA transferred their gaze away from the target earlier with respect to heel contact in the conditions with increased task complexity,  $F(3,45) = 3.685$ ,  $p = .019$ ,  $\eta_p^2 = .77$ . Post hoc analysis showed that in every experimental condition HROA transferred their gaze earlier with respect to heel contact than LROA. Post hoc analysis also revealed that LROA transferred gaze away from the target earlier with respect to heel contact in the condition comprising both obstacles compared with target only. There were no significant differences between conditions for HROA.

The final fixation duration on the target was longer in HROA, as shown by a significant main effect of group,  $F(1,15) = 10.647$ ,  $p = .005$ ,  $\eta_p^2 = .62$ . Overall values for LROA were  $200.4 \pm 100.7$  ms and for HROA were  $409.1 \pm 173.7$  ms. There was a significant interaction between group and condition in the total target fixation time (sum of all target fixations) between gait initiation (first toe off at the start of each trial) and heel contact on the target,  $F(3,45) = 4.203$ ,  $p = .011$ ,  $\eta_p^2 = .83$  (Table 2). Post hoc analysis revealed that HROA fixated the target for significantly longer compared with LROA in the near obstacle and both obstacles conditions.

There was a significant interaction between group and condition,  $F(3,45) = 3.556$ ,  $p = .022$ ,  $\eta_p^2 = .75$ , in the number of individual fixations on the target in the time between gait initiation and heel contact on the target. Post hoc analysis revealed significant differences between groups only in the

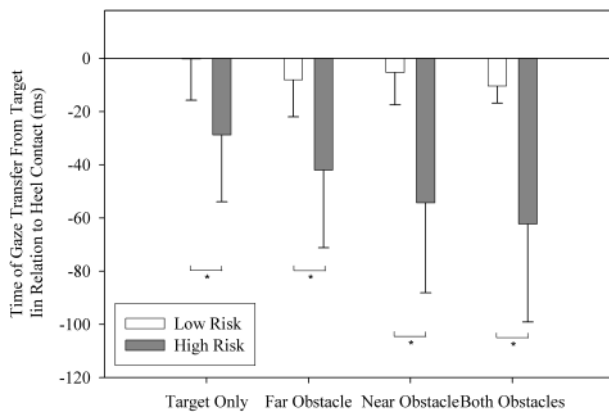


Figure 2. Bars represent the timing of the transfer of gaze from the stepping target relative to the heel contact on it. Negative values represent saccades prior to heel contact. Error bars represent standard deviations.  $p < .05$ .

conditions where one or more obstacles were present, whereby compared with HROA, LROA made significantly more frequent target fixations in the more complex task conditions.

There was a significant interaction between group and condition in the number of fixation transfers from the target to any subsequent obstacle prior to arrival at the target,  $F(2,30) = 11.675$ ,  $p < .001$ ,  $\eta_p^2 = .99$ . Post hoc analysis revealed that compared with HROA, LROA made significantly more fixation transfers from the target to future constraints in the near obstacle and both obstacles conditions (Table 2).

Pearson's Product Moment Correlation analysis showed a significant relationship between duration of the final fixation on the target and the total number of target fixations,  $r(66) = -.666$ ,  $p < .001$ , as well as the timing of gaze transfer from the target,  $r(66) = -.419$ ,  $p < .001$ . These moderate relationships indicate that when the final target fixation was longer, participants were less likely to fixate the target as frequently prior to heel contact and also transfer gaze away from the target earlier with respect to heel contact.

### Stepping Accuracy

There was a significant interaction between group and condition in the number of missed steps,  $F(1,15) = 3.122$ ,

$p = .035$ ,  $\eta_p^2 = .69$  (Figure 3a). Post hoc analysis showed that HROA made a higher number of missed steps in all conditions compared with LROA. HROA also made a higher number of missed steps in all conditions compared with the target-only condition, whereas LROA showed no significant differences between conditions.

Analysis using Pearson's Product Moment Correlation coefficient showed a significant correlation between earlier gaze transfers from the target in relation to heel contact and increases in the percentage number of missed steps on the stepping target  $r(66) = -.678$ ,  $p < .001$ .

### Gait Characteristics

There was a significant main effect of experimental condition on stance,  $F(3,45) = 4.420$ ,  $p = .008$ ,  $\eta_p^2 = .85$ , and swing,  $F(3,45) = 6.260$ ,  $p = .001$ ,  $\eta_p^2 = .95$ , phase durations prior to heel contact on the target. Post hoc analysis revealed that compared with the target-only condition, stance and swing phase durations each increased in both near obstacle and both obstacle conditions. Values for stance phase durations from all participants were target only:  $857 \pm 114$  ms, far obstacle:  $884 \pm 118$  ms, near obstacle:  $889 \pm 104$  ms, and both obstacles:  $897 \pm 102$  ms. Values for stance phase durations from all participants were target only:  $776 \pm 112$  ms, far obstacle:  $783 \pm 87$  ms, near obstacle:  $819 \pm 104$  ms, and both obstacle:  $822 \pm 103$  ms. There were no significant differences between participant groups in walking velocity.

### Self-Reported Anxiety Measures

The results from the SRA inventory showed a significant interaction between group and condition, whereby in comparison with LROA, HROA showed progressively higher anxiety scores in more complex task conditions,  $F(3,45) = 7.983$ ,  $p < .001$ ,  $\eta_p^2 = .99$  (Table 2). Post hoc analysis revealed that only in the conditions where an obstacle was present following the target did HROA self-report higher anxiety levels compared with LROA (Figure 3b). Spearman's rank correlation coefficient analysis showed a significant negative correlation between SRA levels and timing of gaze transfer away from the target,  $r(66) = -.770$ ,

Table 2. Interactions Between Task Condition and Fall Risk Group in Gaze Characteristics and Anxiety Measures

Measure	Low risk				High risk				Group/condition interaction ( $F$ )
	Target only	Far obstacle	Near obstacle	Both obstacles	Target only	Far obstacle	Near obstacle	Both obstacles	
Number of target fixations	$3.1 \pm 1.6$	$3.8 \pm 1.2_a$	$4.2 \pm 1.2_a$	$4.2 \pm 1.1_a$	$2.3 \pm 0.8$	$2.3 \pm 0.9$	$2.5 \pm 0.8$	$2.3 \pm 0.8$	3.55*
Total duration of target fixations	$7.1 \pm 1.1$	$6.5 \pm 1.7$	$5.9 \pm 1.7_a$	$5.7 \pm 1.3_a$	$6.7 \pm 1.1$	$6.6 \pm 0.8$	$6.8 \pm 1.1$	$6.7 \pm 1.0$	4.20*
Number of gaze transfers from target to either obstacle	N/A	$2.9 \pm 1.7$	$3.6 \pm 1.8_a$	$5.2 \pm 2.4_a$	N/A	$1.8 \pm 0.9$	$2.2 \pm 0.7$	$2.7 \pm 1.0$	11.68*
Anxiety (SRA)	$0 \pm 0$	$0 \pm 0_a$	$0.6 \pm 1.5_a$	$1.6 \pm 2.8_a$	$0.8 \pm 0.8$	$1.7 \pm 1.3$	$3.7 \pm 2.2$	$7.7 \pm 4.3$	7.98**

Notes: \*Significantly different to high-risk older adults.

\* $p < .05$ ; \*\* $p < .01$ .

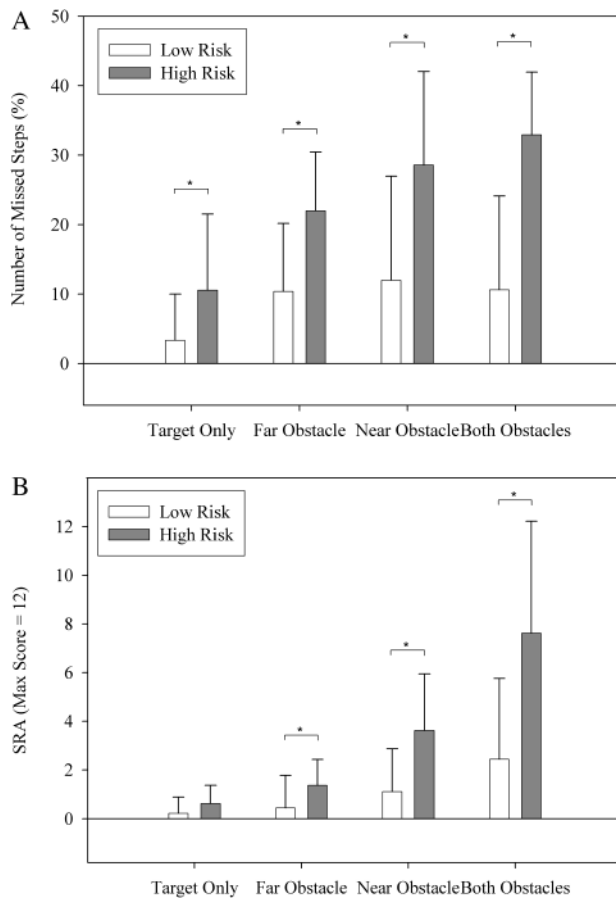


Figure 3. (a) Each bar represents the number of missed steps (foot contacting the stepping target) as a percentage of the total number of trials in each condition. Error bars represent standard deviations.  $*p < .05$ . (b) Each bar represents anxiety levels self-reported by each participant for each of the experimental conditions. Participants completed the 4-point inventory with respect to how they felt during each trial in the time prior to heel contact on the stepping target. Error bars represent standard deviations.  $*p < .05$ .

$p < .001$ . That is, looking away early was associated with greater SRA (Figure 4). Increased SRA levels also correlated with an increased percentage number of missed steps,  $r(66) = .710$ ,  $p < .001$ . After adjusting for SRA measures, results using ANCOVA showed no difference between groups for the time of gaze transfer relative to heel contact. However, results using ANCOVA did show a significant difference between groups in the number of missed steps,  $F(1,14) = 10.918$ ,  $p = .005$ ,  $\eta_p^2 = .87$ . There was a strong relationship between SRA and both the time of gaze transfer from the target and the number of missed steps, as indicated by partial eta squared values of .704 and .752, respectively.

#### EDR Measures

There was a main effect of group,  $F(1,15) = 12.611$ ,  $p = .003$ ,  $\eta_p^2 = .91$ , on the magnitude of EDR. HROA showed a 150% increase in EDR response compared with unconstrained walking, whereas the EDR of LROA was relatively

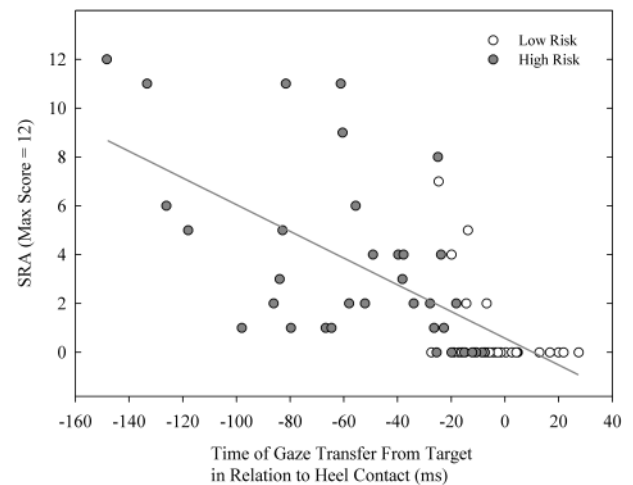


Figure 4. Timing of gaze transfer: each data point represents the mean value for one subject in one of the experimental conditions. SRA: Each data point represents the mean of 3 inventories (taken after 5, 20 and 40 trials) for one of the experimental conditions, for one subject.  $*p < .05$ .

unaffected by the presence of stepping constraints. Overall values for percentage EDR increase for LROA were  $3.97 \pm 108.5$  and for HROA were  $156.74 \pm 182.53$ . Spearman's rank correlation coefficient analysis showed a significant positive correlation between EDR response and SRA,  $r(66) = .347$ ,  $p < .01$ .

#### DISCUSSION

The primary aim of the current experiment was to determine the extent to which gaze behavior and associated decline in stepping accuracy is associated with increased levels of anxiety regarding aspects of the walking task. Our results clearly show that HROA self-reported significantly higher levels of anxiety when negotiating pathways with higher levels of obstacle task complexity (see Figure 3b). We also found significant and large between-group differences in the percentage increase in EDR magnitude during the experimental trials. The measure of EDR is inherently subject to considerable variability, as it is sensitive to many factors such as ambient temperature and movement of the electrodes, especially during a dynamic task like ours. As physiological arousal is indicative of anxiety (Ashcroft, Guimaraes, Wang, & Deakin, 1991), we suggest that the group differences in physiological response provide a general validation for the group differences shown in SRA. Furthermore, we found no between-group differences in STAI measures taken immediately prior to the testing session, supporting the notion that increases in SRA and EDR in HROA were a result of a heightened anxiety response to the tasks present during the session.

Measures of SRA correlated significantly with timing of gaze transfer from the stepping target (with respect to heel contact; Figure 4). Furthermore, after adjusting for measures of SRA, we found that the between-group differences

in the time of gaze transfer from the target were eradicated. In accordance with a previous demonstration of how the perception of threat can influence the direction of visual fixation (Lee & Knight, 2009), the current results suggest that the differences in gaze behavior demonstrated by HROA can be explained, at least in part, by increased anxiety relating to aspects of their future travel path.

Our results show that a significant proportion of between-group differences in stepping inaccuracies (missed steps) were independent of measures of SRA, although a strong relationship was found between the two. Heightened anxiety can inhibit performance in divided attention tasks in older adults (Hogan, 2003) and alter the allocation of attention during adaptive gait (Gage et al., 2003). Therefore, we suggest that increased anxiety may influence stepping accuracy indirectly, through provoking maladaptive visual sampling strategies that are known to compromise stepping accuracy in older adults (Young & Hollands, 2010).

The second aim of our study was to compare the gaze characteristics of HROA and LROA during the approach with stepping targets and determine how these relate to gaze behavior during target negotiation.

Our results clearly show significant differences in gaze behavior between HROA and LROA when approaching the target (Table 2). Collectively, these findings reveal how participants who looked away early from the stepping target (predominantly HROA) spent less time previewing the future travel path and more time fixating the target than participants (predominantly LROA) who looked away later. On average, the LROA group spent more time previewing future obstacles during the approach to the target as complexity increased. Adopting this strategy would have provided participants with advanced visuospatial information describing upcoming constraints, which presumably would have been stored in memory. This strategy may allow participants to fixate stepping targets until around heel contact, thereby maximizing the amount of detailed visual information required for targeting the limb. In contrast, the HROA group tended not to preview upcoming constraints but maintained fixation on the target during the approach. HROA then looked away from the target sooner than LROA, during swing phase of the targeting limb. The extent of early gaze transfer increased in line with increasing task complexity and was associated with a decline in target stepping accuracy and precision.

HROA may fixate future constraints less often as they cannot retain visuospatial information describing the future obstacles long enough to utilize it. Persad and colleagues (1995) found no relationship between visuospatial memory and locomotor characteristics in an obstacle avoidance task. However, deficits in visuospatial memory are likely to be emphasized during tasks where multiple obstacles are encountered (such as the more complex task presented in the current study). Nevertheless, adopting a visual strategy that reduces the duration and number of fixations directed

toward subsequent constraints is likely to reduce the resolution of an internal spatial map regarding those specific obstacles. With respect to heel contact on the target, transferring gaze fixation from the target at an earlier time, in order to fixate the following constraint, may be a way of compensating for deficits in spatial information regarding the future obstacle(s).

It has been suggested that changes in the ability of older adults to process spatial information has consequences for the time that individuals will choose to fixate a constraint in the travel path (Di Fabio et al., 2003). Our results show that HROA transferred their gaze earlier and self-reported higher anxiety levels in the condition of near obstacle compared with far obstacle. Therefore, the timing of gaze transfer is modified when perceived threat level increases regarding the position or time to contact of the upcoming obstacle. This leads to the question: could differences in the perception of threat regarding future obstacles be associated with ability to process visuospatial information? Future work should use more sensitive measures of visuospatial memory and attention capacity to examine how deficits in these areas influence the manner in which visual information regarding multiple constraints is gathered during an approach toward them.

There are limitations in the current study that are important to mention. Although previous studies have used retrospective self-assessments of anxiety (Carpenter et al., 2006; Hauck et al., 2008), such measures are potentially susceptible to a degree of bias within participant responses. Due to the limitations of the eye-tracking equipment, we could not include participants requiring the use of eyeglasses, although two participants wore contact lenses. Very little previous work has attempted to study the influence of wearing eyeglasses on gaze strategies during locomotion. Future work should aim to identify how the results of the current study can be generalized to people who wear eyeglasses and to those with specific deficits in visual function, such as impaired contrast sensitivity. The current data do not include a young sample. However, Chapman and Hollands (2007) showed that young adults do not transfer gaze from a stepping target prior to foot contact inside it, regardless of the number of subsequent constraints in the travel path. As the purpose of the current study was to assess whether the previously shown differences between HROA and LROA in visual and stepping behaviors are associated with anxiety, the inclusion of a young adult sample is not necessary to test our hypotheses.

### *Summary and Conclusions*

Our results demonstrate significant relationships between increased anxiety, changes to gaze behavior, and associated decline in stepping accuracy in HROA during adaptive locomotion. Further work is needed to elucidate the mechanisms underlying age-related changes to psychological function and the coordination of gaze, gait, and postural control.



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## CORRESPONDENCE

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