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EFFECT OF GAZE POSITION AND BLUR ON STEPPING ACCURACY IN OLDER ADULTS

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ABSTRACT

PURPOSE: To examine the effects of gaze position and optical blur, similar to that used in multifocal corrections, on stepping accuracy for a precision stepping task among older adults.

METHODS: Nineteen healthy older adults (mean age 71.6 ± 8.8 years) with normal vision performed a series of precision stepping tasks onto a fixed target. The stepping tasks were performed using a repeated-measures, counterbalanced design for three gaze positions (fixating on the stepping target, as well as 30 cm and 60 cm further forward of the stepping target) and two visual conditions (best-corrected vision and with +2.50DS blur). Participants' gaze position was tracked using a head-mounted eye tracker. Absolute, anterior-posterior (A-P) and medio-lateral (M-L) foot placement errors and within-subject foot placement variability were calculated from the locations of foot and floor mounted retro-reflective markers captured by flash photography of the final foot position.

RESULTS: Participants made significantly larger absolute and A-P foot placement errors and exhibited greater foot placement variability when their gaze was directed further forward of the stepping target. Blur led to significantly increased absolute and A-P foot placement errors, and increased foot placement variability. Furthermore, blur differentially increased the absolute and A-P foot placement errors and variability when gaze was directed 60cm further forward of the stepping target.

CONCLUSIONS: Increasing gaze position further ahead from stepping locations and the presence of blur negatively impacts on the stepping accuracy of older adults. These finding indicate that blur, similar to that used in multifocal corrections, has the potential to increase the risk of trips and falls among older populations when negotiating challenging environments where precision stepping is required, particularly as gaze is directed further ahead from stepping locations when walking.

KEYWORDS: stepping accuracy, blur, visuomotor control, older adults, gaze behaviour

Falls are a significant cause of injury, healthcare utilization, morbidity and mortality among older adults.[1,2] Importantly, older adults with visual impairment are more likely to experience falls compared to their normally sighted counterparts, as shown in population studies[3,4] and in cohorts with specific ocular diseases, such as age-related macular degeneration[5,6] and glaucoma.[7] This increased risk of falls may partially arise from the reduced ability of older adults with visual impairment to extract relevant visual information from the environment to guide safe walking.

The visual impairment from refractive blur, associated with wearing presbyopic multifocal spectacle corrections, including bifocals and progressive lenses, may also contribute to the increased falls risk among older adults, due to the resultant blurring of the lower portion of the field of view. Lord et al[8] found that multifocal wearers were more than twice as likely to fall compared to non-multifocal wearers, particularly when precision stepping tasks were involved, such as stair negotiation. Even in adapted wearers, multifocal corrections have been demonstrated to increase the number of contacts with ground level obstacles,[9] and increase the risk of tripping through greater variability in toe-clearance and foot placement when negotiating raised surfaces,[10,11] compared to single vision lens corrections. Furthermore, adaptive gait changes have been reported in inexperienced multifocal wearers for stepping tasks, including slower stepping speeds and increased toe clearance.[12] Optical blur, of a similar magnitude to that resulting from multifocal corrections, has recently been shown to increase stepping errors.[13] A randomized control trial found that the provision of single vision distance spectacles for multifocal wearers significantly reduced the rate of falls among older adults who took part in regular outdoor activities.[14]

Coordinated visuomotor stepping control is required to walk safely through the environment, where accurate visual identification of potential hazards guides appropriate planning and execution of the lower limb trajectory and foot placement.[15] In uncluttered environments where there are no constraints on foot placement for safety, such as an unobstructed, level footpath, gaze is generally directed several steps ahead and visual information is used in a feedforward manner for path planning.[16] However, in challenging or cluttered environments where precision foot placement is crucial for safety, such as stair negotiation, gaze is directed downward towards the area of the stepping location, facilitating accurate visual localization of the stepping location and optimizing the accuracy of the endpoint foot placement.[16,17] In these precision stepping situations, vision is used in a feedback, or online, manner to continuously adjust foot trajectory during the step action to improve stepping accuracy, followed by a gaze transfer away from the stepping location as the foot contacts the ground.[18,19] Importantly, poor stepping accuracy has been identified as a potential indicator of falls risk among older adults.[19,20]

Age-related differences in stepping gaze behaviours, where some older adults prematurely transfer their gaze away from the foot landing locations prior to placing their foot on the ground have also been demonstrated.[19] This strategy may assist in planning of future stepping actions in challenging visual environments, but at the cost of reduced stepping accuracy and precision.[19] Indeed, there is evidence that older adults can improve stepping accuracy by altering their gaze behaviour to maintain fixation on stepping targets until heel contact is made.[21] Importantly, prematurely transferring gaze further ahead from a stepping target relies on the use of the inferior visual field to guide the final foot placement. The use of non-foveal visual information has been shown to reduce stepping placement accuracy in young participants, when laterally viewing a stepping target (around 10 degrees to the right and left) compared to directly viewing the target.[22]

Previous research thus highlights the importance of using visual information to guide spatial planning of stepping location, and the impact of visual impairment from blur. The aim of the present study was to investigate the impact of optical blur, similar to that resulting from commonly prescribed presbyopic multifocal corrections, and the location of gaze on the stepping accuracy of older adults during a precision stepping task in order to better understand potential mechanisms underlying the increased falls risk seen with these corrections. Participants included current multifocal wearers and non-wearers to also assess whether existing multifocal wearers would exhibit less problems with blur given they should have already been adapted to blur at ground level.

METHODS

Participants

Nineteen community-dwelling older adults (11 female, 8 male; mean age 71.6 ± 8.8 years, range 53-85 years) were recruited from the QUT Optometry Clinic. Participants were independently mobile, and were excluded if they had any significant ocular disease, or any neurological or musculoskeletal disorders which could affect their balance or gait. Participants were excluded if best corrected visual acuity was worse than 0.1 log MAR in either eye (6/7.5, 20/25 Snellen equivalent) or had any significant cataracts (graded 4.0 or worse as defined by the Lens Opacities Classification System[23]). The research followed the tenets of the Declaration of Helsinki, and informed consent was obtained before participant assessment. The study was approved by the Queensland University of Technology Human Research Ethics Committee.

Visual function assessment

Binocular visual acuity and contrast sensitivity were measured with the best-corrected refractive correction, which was determined subjectively at the time of the study. Visual acuity was measured with a high-contrast logMAR chart using a letter by letter scoring system at 5 m with a chart luminance of 125 cd/m^2. Contrast sensitivity was measured binocularly using the paper version of the Melbourne Edge Test (MET), at a working distance of 40 cm using an appropriate near correction and an average luminance of 65 cd/m^2. The MET is a four alternative forced-choice edge detection test, where participants are asked to identify the orientation of the edge within each circular patch until two consecutive incorrect responses are made, and the lowest contrast edge correctly identified recorded as the participant's contrast sensitivity in decibels. Monocular visual fields were assessed using a 40 point screening test (Model HFA-II 750m; Carl Zeiss Meditec, www.zeiss.com) to ensure participants had no visual fields defects. The habitual spectacle correction design worn by participants was recorded.

Experimental protocol

For the precision stepping task, participants were instructed to take a single step forward on the same level at a self-selected pace, from a stationary standing position, leading with their dominant foot and placing this foot as accurately as possible onto a stepping target located directly in front of them, as shown in Figure 1. The stepping target comprised a contour of each participant's stepping foot, which had been previously drawn using a white marker onto the grey floor surface (Weber contrast 8%), and was positioned 30cm in front of the starting position, which approximated an average step length.[22] Foot dominance was determined according to participants' reported preference for kicking a ball.

Prior to each stepping trial, participants were instructed to fixate on one of three gaze positions: (i) on the stepping target (aligned with the toe position), (ii) 30 cm further forward or away from the stepping target (30 cm gaze position) or (iii) 60 cm further forward or away from the stepping target (60 cm gaze position). The gaze positions were indicated by yellow dots on the floor. The angular difference between each of the gaze positions was around 10 degrees, based on an average person height of 160 cm.

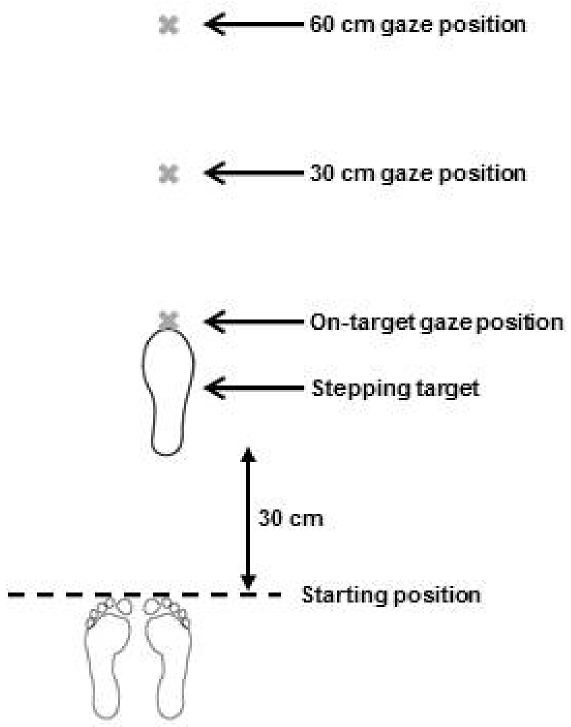

Figure 1: Schematic of the experimental set up of the precision stepping task.

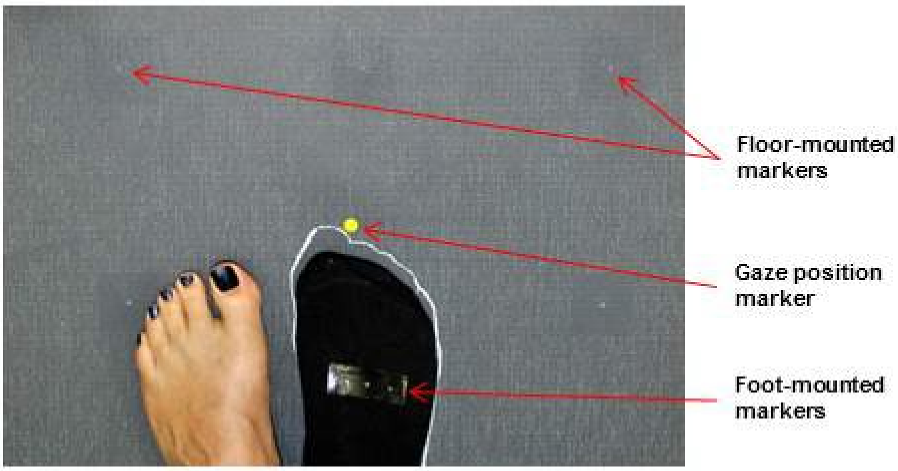

Figure 2: Example of a completed step foot position, showing the foot-mounted, floor-mounted and gaze position markers.

Participants completed the stepping tasks under two visual conditions using their best-sphero-cylinder spectacle correction, and with an additional +2.50 DS blur, to reflect the blur resulting from commonly prescribed multifocal lens additions for patients aged 70 years and over, who are those older adults most at risk of falling. For each visual condition, standard single vision trial lenses (38 mm diameter) were mounted into Halberg trial lens clips fitted into the eyetracker googles. Participants performed 10 trials for each combination of gaze position and visual condition, resulting in a total of 60 (10x3x2) stepping trials. The conditions were presented in randomized blocks for each vision and gaze position combination. Participants were provided with several practice trials prior to testing.

Participants wore socks for all stepping trials, onto which three retro-reflective markers were mounted (Figure 2). Five fixed floor mounted retro-reflective markers were also located under the small perforations (around 0.5mm diameter) of the grey flooring, which were inconspicuous to participants. After each step, the final foot position was recorded using a flash high-resolution digital camera (Nikon D3000; Nikon, www.nikon.com; 10 megapixels, 3872 × 2592 pixels) mounted on a tripod above the stepping target, which captured the reflected light from the foot and floor-mounted retro-reflective markers. A reference step was generated from a photo of each participant's foot positioned directly in the center of the stepping target prior to experimental testing. Photographs were taken of a standard ruler prior to testing each participant to calibrate the pixel to length ratio. For each trial photograph, the center pixel co-ordinates of the foot and floor markers (which subtended around 5 pixels in diameter) were determined by a single-masked grader. Analysis of localization errors for the fixed floor-based markers for the 60 trials across participants showed low variability, with a standard deviation of less than 1 pixel (~ 0.2 mm).

A head-mounted eye-tracker (ASL MobileEye; Applied Science Laboratories; www.asleyetracking.com) was used to monitor gaze position in real-time during each step. For the 30 cm and 60 cm gaze position trials, participants were instructed to view the stepping target before directing their fixation to the appropriate gaze position. Trials were repeated if gaze was not maintained at the appropriate position for the complete stepping action.

Data and Statistical Analysis

For each stepping trial, the midpoint of the foot in the landing position was calculated as the mean position of the two lateral foot markers. Absolute foot placement error was calculated as the Euclidean distance between the midpoint of each step and the midpoint of the reference step. Anterior-posterior (A-P) and medio-lateral (M-L) foot placement errors were calculated in a similar fashion, using the A-P and M-L distances between the midpoints of each step and the reference step. Within-subject foot placement variability was quantified using the standard deviations for the respective absolute, A-P and M-L foot placement errors.

For this repeated measures design, a series of random intercept linear mixed models were fitted to assess changes in stepping parameters for the blur and gaze conditions, using the maximum likelihood procedure in SPSS (Version 21.0, http://www-01.ibm.com/software/analytics/spss/). The covariance structure utilized was autoregressive, to account for the correlation among repeated measures, based on the Akaike Information Criterion.[24] Separate analyses were conducted for each of the stepping measures, with each model incorporating a random intercept for participants, and fixed effects of gaze position (three levels: on-target, 30 cm and 60 cm), visual condition (two levels: best-corrected, +2.50 DS blur) and an interaction term. Stepping sequence and condition order were also included in the models as fixed effects, as they significantly improved the model fits and adjusted for potential learning effect with repeated stepping trials. Any significant main effects or interactions were examined using Bonferroni-adjusted post-hoc comparisons.

To further explore whether habitual spectacle correction influenced the stepping measures, a variable for habitual spectacle type (non-multifocal vs. multifocal correction) was also included in these models to test our hypotheses that existing multifocal wearers would exhibit better stepping accuracy and less variability under the blur conditions than non-multifocal wearers given they should already be adapted to blur at ground level.

RESULTS

For the best-corrected vision condition, mean binocular visual acuity was -0.04±0.07 logMAR and MET contrast sensitivity was 21.7±1.1. The +2.50 DS blurring lenses reduced binocular visual acuity to 0.54±0.13 logMAR, Participants regularly wore a range of spectacle corrections when walking: 9 did not wear any multifocal correction (8 no correction, 1 single vision distance), and 10 wore a multifocal correction (5 bifocals, 5 progressives). Means and standard deviations of the stepping outcomes measures are presented in Table 1.

Table 1: Means values and SD for stepping parameters.

	On Target		30cm ahead		60cm ahead	
	Best-corrected	+2.50 DS Blur	Best-corrected	+2.50 DS Blur	Best-corrected	+2.50 DS Blur
Stepping Accuracy						
Absolute Foot Placement Error (mm)	11.1 ± 7.0	11.6 ± 7.6	15.6 ± 9.5	15.9 ± 9.1	19.5 ± 10.6	24.6 ± 17.1
Anterior-posterior Foot Placement Error (mm)[a]	1.0 ± 11.0	1.1 ± 12.3	0.5 ± 16.8	-2.5 ± 15.7	3.4 ± 19.2	-3.3 ± 27.8
Medio-lateral Foot Placement Error (mm)[b]	0.1 ± 6.9	1.1 ± 6.3	1.1 ± 7.3	1.3 ± 9.2	-0.1 ± 10.6	0.6 ± 10.6
Stepping Precision						
Absolute Foot Placement Variability (mm)	6.4 ± 1.8	6.5 ± 3.1	8.3 ± 2.1	8.7 ± 2.3	9.2 ± 3.1	12.3 ± 4.2
Anterior-posterior Foot Placement Variability (mm)	9.9 ± 3.6	10.7 ± 3.9	12.3 ± 2.5	12.7 ± 4.5	13.7 ± 5.2	17.4 ± 6.7
Medio-lateral Foot Placement Variability (mm)	5.1 ± 1.6	5.0 ± 1.9	6.1 ± 1.8	6.9 ± 3.2	7.1 ± 1.1	7.0 ± 2.4

[a] More positive values reflect more anterior foot position (over-step)
[b] More positive values reflect more medial foot position

Stepping Accuracy – Foot Placement Errors

There were significant main effects of gaze position ($F(2,298)=53.8$, $p<0.001$) and visual condition ($F(1,411)=13.8$, $p<0.001$) on absolute foot placement error. There was also a significant gaze position x visual condition interaction on absolute foot placement error ($F(2,356)=5.6$, $p=0.004$, Figure 3). For both visual conditions, post-hoc comparisons revealed that absolute stepping errors were significantly larger with increasing gaze eccentricity from the target ($p<0.05$). Furthermore, absolute stepping errors were significantly larger with +2.50DS blur at the 60 cm gaze position compared to best-corrected vision ($p=0.001$).

In the A-P direction, there was a significant main effect of visual condition on foot placement errors ($F(1,420)=16.2$, $p<0.001$), but no significant main effect of gaze position ($F(2,271)=2.0$, $p=0.13$). However, there was a significant gaze position x visual condition interaction ($F(2,347)=5.4$, $p=0.005$). With best-corrected vision, post-hoc comparisons revealed that participants over-stepped onto the target (more anterior foot placement) when viewing the 60 cm gaze position, compared to the on-target and 30 cm positions ($p=0.025$). With +2.50DS blur, participants significantly under-stepped onto the target (more posterior foot placement) at the 30 cm and 60 cm gaze positions, compared to the on-target position ($p<0.027$), but this was not evident when directly viewing the target ($p=0.67$). Furthermore, the +2.50DS blur resulted in significantly more under-stepping errors onto the target for both the 30 cm and 60 cm gaze positions compared to best-corrected vision ($p<0.026$).

In the M-L direction, there was no significant main or interaction effects of gaze position or visual condition on foot placement errors ($p>0.05$).

Stepping Precision - Within-Subject Foot Placement Variability

There were significant main effects of gaze position ($F(2,48)=31.3$, $p<0.001$) and visual condition ($F(1,32)=10.3$, $p=0.003$) on absolute foot placement variability, as well as a significant gaze position x visual condition interaction ($F(2,85)=5.7$, $p=0.005$; Figure 4). With best-corrected vision, variability was significantly larger when viewing the 30 cm and 60 cm gaze positions than the on-target position ($p<0.048$). With +2.50DS blur, variability was significantly larger with increasing gaze eccentricity from the target ($p<0.019$). Furthermore, absolute stepping variability was significantly larger with +2.50DS blur at the 60 cm gaze position than with best-corrected vision ($p=0.001$).

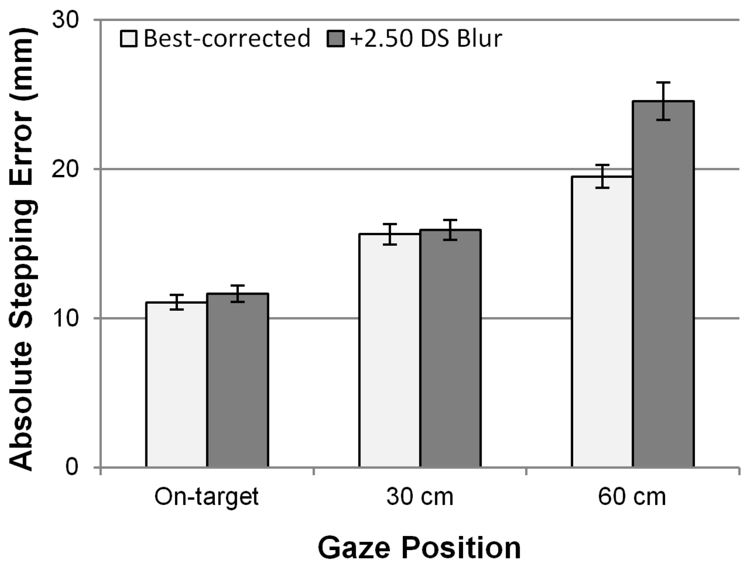

Figure 3: Group mean (± SE) for absolute stepping error, as a function of gaze position and visual condition. For both visual conditions, absolute stepping errors were significantly larger with increasing gaze eccentricity from the target (p<0.05). At the 60 cm gaze position, absolute stepping errors were significantly larger with blur compared to best-corrected vision (p=0.001).

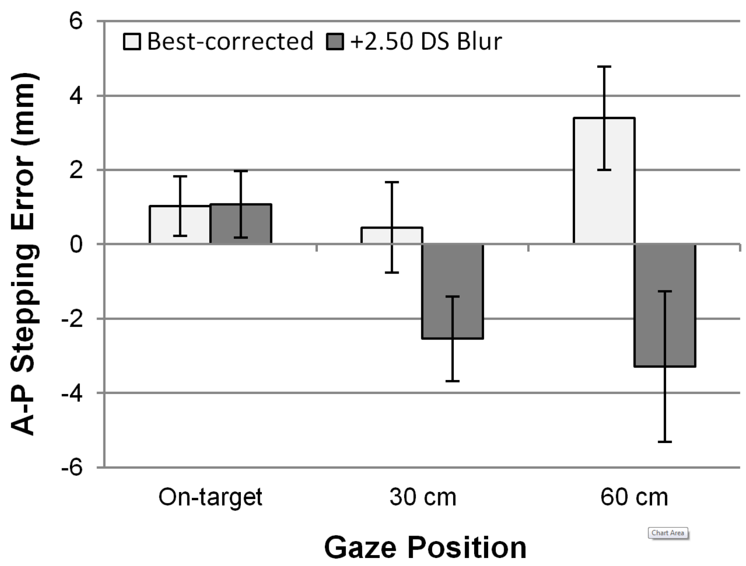

Figure 4: Group mean (± SE) for A-P stepping error, as a function of gaze position and visual condition. Negative y-axis values correspond to under-stepping (more posterior foot placement). With blur, participants significantly under-stepped onto the target at the 30 cm and 60 cm gaze positions compared to the on-target position (p<0.027), as well as compared to the corresponding best-corrected vision condition (p<0.026).

In the A-P direction, there were significant main effects of gaze position ($F(2,48)=16.0$, $p<0.001$) and visual condition ($F(1,37)=9.3$, $p=0.004$) on foot placement variability, as well as a significant gaze position x vision condition interaction ($F(2,85)=4.0$, $p=0.022$). With best-corrected vision, post-hoc comparisons revealed a difference in A-P stepping variability only between the 60 cm and on-target gaze position ($p=0.04$). With the +2.50DS blur, significantly larger variability was found between the 60 cm gaze position, compared to the on-target and 30 cm positions ($p<0.001$). Furthermore, A-P stepping variability was significantly larger with +2.50DS blur at the 60cm gaze position than with best-corrected vision ($p=0.005$).

In the M-L direction, there was a significant main effect of gaze position on foot placement variability ($F(2,52)=10.2$, $P< 0.001$), showing greater variability for the 30cm and 60cm gaze positions, compared to the on-target position. There was no main effect of visual condition ($F(1,41)=0.6$, $P=0.43$) or an interaction effect ($F(2, 87)=0.5$, $P=0.63$) for M-L foot placement variability.

When habitual spectacle correction was also included in the analyses, no significant differences were found between multifocal and non-multifocal wearers across all of the stepping measures ($P=0.23$ to 0.77), however, post-hoc power analysis indicated that the sample size provided only 19% power to detect differences across stepping outcomes between the groups at a level of $\alpha = 0.05$.

DISCUSSION

The results of this study indicate that stepping accuracy and precision is reduced among healthy, normally-sighted older adults when gaze is directed further ahead from the immediate stepping location, as shown by increased foot placement errors and variability. Furthermore, optical blur reduced stepping accuracy and precision, and compounded the effect of gaze position, particularly when gaze was positioned 60 cm further forward of the stepping target. These findings are important, given that many older adults wear multifocal spectacle corrections when walking, and the feed forward nature of visual control when walking, means that their gaze is generally directed around two steps ahead of the target.[25]

Precision stepping tasks require gaze fixations towards a stepping target prior to initiation of the foot swing to step onto a target, using vision in an online manner to adjust foot trajectory during the step action to optimize stepping accuracy, followed by saccadic eye movements away from a stepping target as the heel of the foot contacts the target.[16,18,19] Importantly, some older adults demonstrate premature gaze transfer prior to foot placement, to the detriment of their stepping accuracy.[19] Our study supports these previous findings, highlighting the importance of maintaining gaze position on the stepping targets to maximize stepping accuracy and precision. When gaze is directed ahead of the stepping target, the inferior peripheral visual field is used to modulate limb trajectory and guide foot placement, and our findings indicate that this does not provide the level of visual information required for a precision stepping task. Our findings also support the benefits of gaze training, to maintain gaze position on stepping locations when undertaking precision stepping tasks, to improve stepping accuracy and minimize the risk of trips or slips, particularly in older adults at high risk of falls.[21] Although the observed magnitude of stepping errors in this study are not high, as measured using a simple stepping task under controlled conditions, there are many challenging environments in the natural environment where foot placement position is crucial for safety, such as when negotiating stairs or uneven pavements, where even small errors in foot position may be enough to instigate a trip or fall.

The findings of the present study agree with recent research which demonstrated that viewing targets laterally, around 10 degrees to the left and right of a stepping target, resulted in greater stepping errors and variability, compared to on-target viewing, in a group of young, healthy participants.[22] However, a lateral gaze position is unlikely to reflect natural gaze position when walking, as individuals tend to look further forward along the travel path when walking.[25]

Blur also significantly increased stepping errors and variability, which is consistent with previous research showing reductions in stepping accuracy with greater levels of refractive blur.[13] Importantly, blur significantly interacted with gaze position, where stepping errors and variability was greatest under the blur condition, particularly when gaze was directed 60 cm ahead of the stepping target. Furthermore, blur resulted in significant under-stepping errors in the A-P direction at the 30 cm and 60 cm gaze positions, most likely from the spectacle magnification effect of the +2.50 lenses;[26] however, no under-stepping errors were found when gaze was directed at the stepping target. Thus older adults at high risk of falls might benefit from single vision glasses to improve stepping accuracy, in addition to training to maintain gaze position on stepping locations until heel contact.[21]

There was no evidence in the current study to suggest that older adults regularly wearing multifocal corrections differed in their precision stepping behaviours under any of the visual conditions compared to non-multifocal wearers. This suggests that habituation to blur from regular multifocal wear may not lead to improvements in stepping accuracy, and supports the benefits of prescribing single vision lenses, particularly in active older adults.[14] However, our findings must be interpreted with caution, given the small sample size (post-hoc power analyses of all group comparisons were less than 80%). In addition, the single vision lenses used in the present study do not incorporate any peripheral distortion or image jump effects which are present in multifocal lenses, which may also impact on stepping accuracy. Further research with larger samples is needed to explore these effects ~~of~~ for both single vision and multifocal corrections on visuomotor control.

The present study provides novel information pertaining to the contribution of vision to precision stepping, in a well-controlled repeated measures design, using eye-tracking technology to ensure accurate gaze position for all trials. The novel approach using high-resolution still photography provided robust estimates of stepping position, but further research is warranted to compare our findings with those derived using standard motion capture technology. The study was also limited by its sample size, which was not powered to detect between-group differences for multifocal and non-multifocal wearers. In addition, the stepping task, while having the advantage of providing a controlled and repeatable task, may not completely represent gaze and stepping within natural environments, where gaze might be redirected towards the stepping location during the swing phase of the leg to make corrections. Furthermore, the set stepping length used in this study may not have corresponded to participants' preferred step length, and future work should consider scaling of this length according to participants' height. Lastly, healthy, active participants were included, so the results cannot be generalized to frailer, less independent older populations. Therefore, further research is needed to examine how stepping precision is affected among older adults at higher risk of falling, including those with vision impairment from ocular disease.

In conclusion, this study provides important insights into the contribution of vision to the spatial planning of precision steps, highlighting the detrimental effects of increasing gaze position away from imminent stepping locations and visual impairment from optical blur. These finding indicate that blur, similar to that used in multifocal corrections, has the potential to increase the risk of trips and falls among older populations when negotiating challenging environments where precision stepping is required, particularly as gaze is directed further ahead from stepping locations when walking.

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