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Adaptive gait changes due to spectacle magnification and dioptric blur in older people

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Running head: Spectacle magnification drives adaptive gait

ABSTRACT

Purpose. A recent study suggested that updated spectacles could increase falls rate in older people. We hypothesized that this may be due to changes in spectacle magnification and this study assessed the effects of spectacle magnification on adaptive gait.

Methods. Adaptive gait and visual function was measured in 10 older adults (mean age 77.1 ± 4.3 years) with the participants' optimal refractive correction and when blurred with +1.00DS, +2.00DS, -1.00DS and -2.00DS lenses. Adaptive gait measurements for the lead and trail foot included foot position before the step, toe clearance of the step edge and foot position on the step. Vision measurements included visual acuity, contrast sensitivity and stereoacuity.

Results. The blur lenses led to equal decrements in visual acuity and stereoacuity for the +1.00DS and -1.00DS and the +2.00DS and -2.00DS lenses. However, they had very different effects on adaptive gait compared to the optimal correction: Positive blur lenses led to an increased distance of the feet from the step, increased vertical toe clearance and reduced distance of the lead heel position on the step. Negative lenses led to the opposite of these changes.

Conclusion. The adaptive gait changes did not mirror the effects of blur on vision, but were driven by the magnification changes of the lenses. Steps appear closer and larger with positive lenses and further away and smaller with negative ones. Magnification likely explains the mobility problems some older adults have with updated spectacles and after cataract surgery.

Key words: Spectacle magnification; dioptric blur; adaptive gait; falls

Introduction

Incidences of falling in older adults have been consistently linked to problems with step or stair negotiation.[1-3] Vision is thought to play a major role in successful stair negotiation,[3-5] and age-related deterioration in vision is believed to be a significant factor contributing to the difficulties that older adults experience with stair negotiation.[3] The most common causes of visual impairment in older adults in developed countries are cataract and uncorrected refractive error, both of which are correctable.[6, 7] Jack et al. [8] found a particularly high prevalence (76%) of visual impairment in patients admitted to a hospital clinic due to falls and reported that 79% of these visual impairments were reversible, mainly by updating spectacles (40%) or by cataract surgery (37%). Laboratory-based studies have also shown that postural stability is significantly worse with refractive blur [9] but patients have improved mobility-orientation [10] and balance control after cataract surgery.[11]

These epidemiological, clinic and laboratory-based studies would strongly predict a beneficial effect of correcting refractive error and performing cataract surgery on the likelihood of older adults falling. The prevalence data of correctable visual impairment further suggest that this could have significant benefits to the older population. However, intervention studies on falls rates to date have not shown the expected results. Day et al. [12] examined changes in falls rate after exercise, home hazard management, and treatment of poor vision (a referral to their usual eye care provider for those with poor vision), and found no significant effect of vision treatment alone. Of the four cataract surgery intervention trials, two have shown a slight decrease in falls rate post-surgery,[13, 14] while the other two reported no change in falls rate.[15, 16] A recent optometric intervention study by Cumming et al. [17] may shed some light on these findings. Approximately 300 frail older adults received an optometric intervention and obtained updated spectacles, while participants in the control group were left to their own devices. The study very surprisingly found an increased rate of falls in the intervention group. The authors proposed that the patients in the intervention group might have had difficulty adapting to significant changes in refractive condition during the initial period of wearing new spectacles. As most patients need an updated refractive correction after cataract surgery or obtain a reduction in refractive error during the procedure (due to the provision of an appropriately powered intra-ocular implant that replaces their cataractous lens[18]) perhaps difficulties in adapting to a new refractive error and/or new spectacles is also the reason why cataract surgery does not always provide the expected benefit in terms of a reduced falls rate. A possible cause of difficulties adapting to new spectacles and intra-ocular implants is a change in spectacle or ocular magnification, in that myopic shifts in refractive correction cause minification and hyperopic shifts cause magnification (for example, Garcia et al. [19]; Applegate & Howland [20]).

In this study we assessed the adaptive gait changes that occur when vision is blurred by equal amounts of myopic and hyperopic dioptric blur. We hypothesised that either (1) the dioptric blur would lead to safety gait adaptations that older adults use under conditions of diffuse blur, such as increased lead toe clearance over the step edge [21]; (2) Gait adaptations would respond to the spectacle magnification. For example, additional myopic lenses could lead to a reduction in toe clearance as the step would look smaller and further away due to minification; (3) Some combination of 1 and 2.

Methods

The tenets of the Declaration of Helsinki were followed and the study had approval of the University of Bradford Ethics Committee, with written informed consent being obtained from all participants. Ten participants (3 males, mean age 77.1 ± 4.3 years; height 161 ± 9 cm; mass, 73.5 ± 16.3 kg) were recruited from the University Eye Clinic. Participants were excluded from the study if they had any history of neurological, musculoskeletal or cardiovascular disorders that could affect their balance or gait, or had a history of eye disorders. All participants had good visual acuity (better than 0.1 logMAR, Snellen equivalent 20/25) in both eyes and good depth perception (60 seconds of arc or better on the TNO stereoacuity test). All participants were able to negotiate and complete the experimental task unaided.

The optimal refractive correction at 4m was determined for each participant using focimetry and subjective refraction techniques, including Jackson cross-cylinder evaluation for astigmatism.[22] Binocular visual acuity and contrast sensitivity and stereoacuity were measured with the optimal refractive correction and dioptric blur trial lenses of +1.00DS (a positive spherical lens of power 1.00 dioptre, causing light from a distant object to converge to a focal point of 1/1.00 = 1m), +2.00DS, -1.00DS and -2.00DS (a negative spherical lens of power 2.00 dioptres, causing light to diverge from a virtual focal point of 1/2.00 = 0.5m) using a randomised order of measurement. Binocular visual acuity was measured using a high contrast ETDRS chart at 4m with a chart luminance of 160 cd/m^2, using a by-letter scoring system and a termination rule of 4 letters incorrectly called.[22] Binocular letter contrast sensitivity was measured using a Pelli-Robson chart at 1m with a chart luminance of 200 cd/m^2, using additional working distance lenses of +0.75DS, using a by-letter scoring system and counting the identification of a letter C as an O as correct.[22] Stereoacuity was measured using the TNO stereoacuity test at 40cm with the optimal refractive correction incorporating reading addition lenses of +2.25DS. Stereoacuity was recorded as the highest level where responses were correct for both target pairs on plates V to VII.[22]

Each participant completed 21 stepping trials, which consisted of the participant walking up to a 152mm raised surface from two walking pace lengths away and then stepping onto it and remain stationary once on the raised surface. Two walking paces were chosen as fixation of a step/obstacle in the travel path most frequently occurs at two step lengths from its edge.[23] The raised surface was constructed from medium density fibreboard and plywood and was covered in the same green vinyl as the surrounding floor. The laboratory was well lit with ambient illuminance of 400 lux measured at eye level. A member of the research team was positioned near the front edge of the step to ensure that if participants should trip or stumble they did not fall. Throughout the experiment subjects wore their own, low-heeled or flat soled shoes, and comfortable clothing. Subjects were free to choose which foot to lead with, but once chosen, they were required to repeatedly lead with the same foot. Their adaptive gait was assessed under the optimal refractive correction for the start position to the step edge (measured to be 1.79m ± 0.08m for the 10 participants, so that +0.25DS was added to the 4m refractive correction) and with +2.00DS, +1.00DS, -1.00DS or -2.00DS binocular refractive blur using trial case lenses in a trial frame which was adjusted to fit each participant. Each trial was repeated three times giving a total of 15 stepping measurements for each participant. In addition, four "dummy trials" were included, where the height of the step was randomly adjusted by -10mm or +5mm every fourth trial to limit the effectiveness of using somatosensory feedback from previous trials to estimate the height of the step. No data were collected during these trials and participants were advised that the height of the step would be varied throughout the study. The order of all adaptive gait measurements was randomised.

Three-dimensional lower limb segmental kinematic data of the stepping action were collected (at 100Hz) using an eight-camera, motion capture system (Vicon MX; Oxford Metrics Ltd, Oxford, UK). Reflective markers (6mm on feet, 14mm diameter on other locations) were attached either directly onto the skin, clothing or shoes in the following locations: superior aspects of the 2nd and 5th metatarsal heads, end of 2nd toes, lateral malleoli and posterior aspect of the calcenai. Markers were also placed on the upper front edge of the step to determine its location and height within the laboratory coordinate system. A virtual marker, representing the inferior tip of the shoe (virtual shoe tip) was determined by reconstructing its position relative to the markers placed on the 2nd and 5th metatarsal heads and end of 2nd toe. The 3D coordinate data of each foot marker (including the virtual shoe tip), and the markers placed on the raised surface were exported in ASCII format for further analysis. More details regarding the measurement of the gait/stepping parameters analysed can be found in an earlier report.[21]

Level of significance was set at $p < 0.05$, and post-hoc comparisons were conducted using Tukey HSD. Statistical analyses were performed using Statistica version 5.5 (StatSoft, Inc. Tulsa, OK, USA).

Results

The mean binocular visual acuity, contrast sensitivity and stereoacuity data are shown in Table 1. Dioptric blur had minimal effect on Pelli-Robson contrast sensitivity (p = 0.06), but caused large changes in binocular visual acuity ($p < 0.001$) and stereoacuity ($p < 0.001$). Visual acuity and stereoacuity losses were greater at ±2.00DS than ±1.00DS (post-hoc, p <0.05), but losses were essentially equal at the same dioptric level. For example, visual acuity was reduced to about 0.04 logMAR ($20/20^{-2}$) for both +1.00DS and -1.00DS and to 0.30 logMAR (20/40) for both +2.00DS and -2.00DS.

The mean and 1 SD data of adaptive gait parameters during adaptive gait are shown in Table 1. Several parameters were significantly affected by dioptric blur: Trail foot position before the step (p<0.001), lead vertical toe clearance ($p < 0.001$; see Figure 1), lead horizontal toe clearance ($p < 0.001$), trail horizontal toe clearance ($p < 0.0001$) and lead heel position on the step ($p < 0.001$; see Figure 2). Equal values of dioptric blur led to very different changes in adaptive gait as +1.00DS and +2.00DS led to much larger values than -1.00DS and -2.00DS, respectively, (post-hoc $p < 0.05$) for trail toe position before the step, lead vertical toe clearance, lead horizontal toe clearance, trail horizontal toe clearance and smaller values for lead heel position on the step (see Table 1 and Figures 1 and 2). Trail vertical toe clearance (p = 0.65), swing duration (p = 0.51) and lead foot position before the step (p = 0.09) were all unaffected by dioptric blur.

In 18 trials (12% of all trials) from six subjects, a momentary loss of balance (typically in the +2.00DS blur condition a momentary loss of balance was witnessed. The trail foot and/or arm movements were used to help regain balance) or compensatory movement strategy (often an additional small step or shuffle on the step) was used. This occurred most with +2.00DS (9 trials, 30% of all trials with this lens) and did not occur at all with the optimal refractive correction.

Discussion

The positive and negative dioptric blur lenses had similar effects on visual acuity and stereoacuity and losses were essentially the same at the same dioptric level i.e. visual acuity was reduced to 0.30 logMAR (20/40) and stereoacuity to about 2.55 log seconds of arc (355”) for both +2.00DS and -2.00DS (see Table 1).

Previous results from studies investigating the effects of diffuse blur on adaptive gait [21] would suggest that the dioptric blur would lead to safety strategies such as increased vertical toe clearance being used, because the blurred vision and reduced depth perception made the step edge difficult to locate in the travel path. Given the similar levels of visual acuity and stereoacuity loss for the same amount of dioptric blur, if vertical toe clearance was driven by blurred vision a U-shaped function would be expected with vertical toe clearance being smallest with the optimal correction and increasing to a similar level for +1.00DS and -1.00DS and increasing further with +2.00DS and -2.00DS (see Figure 1, dashed line).

However, the effects on stepping strategies appear to have been driven by their magnification effect on the position and size of the step. The dioptric lenses gave magnification effects of +3.60% (+2.00DS), +1.75% (+1.00DS), -1.70% (-1.00DS) and -3.30% (-2.00DS) as determined by calculation from the curvature, thickness and refractive index of the lenses and their distance from the eye. Gait changes indicated that the step appeared further away and smaller with minus lenses or closer and taller with plus lenses. For example, as the step looked further away with negative lenses, the trail foot position before the step was placed significantly closer to the actual step than the control condition. The step looked closer with positive lenses, the trail foot position before the step was placed significantly further away from the actual step than the control condition. The minification of the step with negative lenses meant that vertical toe clearance was reduced with -1.00DS and -2.00DS. Similarly, magnification of the step with positive lenses increased vertical toe clearance. Given the reduction in toe clearance with negative lenses compared with the optimal refractive correction, the increased toe clearance (and other adaptive gait changes) with positive lenses do not appear to be a safety strategy, but essentially driven by the magnification changes.

Spectacle magnification effects also change the vestibulo-ocular reflex (VOR) gain,[24] which links the vestibular system with the extra-ocular muscles and produces the rapid compensatory eye movements needed to maintain stable vision of an object of interest as the head moves. With changed magnification due to spectacles, the eyes have to move faster (myopic change in correction) or slower (hyperopic change) than before to match head movement speed and this new relationship has to be relearned.[25, 26] Prior to this occurring, the world 'swims' [24] as some patients report. It is of interest that declines in the VOR with age have been linked with gait and balance measures and could suggest a common mechanism.[27] Changes in astigmatism (a rugby-ball shaped front surface of the eye leading to the need for different refractive correction along perpendicular meridians and common in spectacle wearers) can cause even more problems because different amounts of magnification occur along two meridians, so that objects look distorted. Symptoms can include walls, doors and floors sloping.[22, 28] Clinicians suggest that adapting to new spectacles is more difficult for older adults [22, 28] and it is certainly a major concern for elderly patients attending an eye examination.[29] For these reasons some clinicians recommend only prescribing partial changes in refractive error, particularly in older patients.[22, 28] Unfortunately, these recommendations are not supported by any research evidence (they are based on clinical wisdom gained from dissatisfied patients who return to complain about their spectacles) and do not appear to be widely used (for example, Cumming and colleagues[17]). Certainly the magnification effects of changing spectacles and having cataract or refractive surgery focus on the positive effect on visual acuity with myopia reduction[19,20] and previously there has been no thought to the effect of ocular or spectacle magnification on mobility and falls. Clearly, further research is needed to investigate the effects of ocular and spectacle magnification on mobility and also whether reducing the extent of magnification changes due to cataract surgery and/or new spectacles will help adaptation in older adults. In the meantime, given the apparent increase in falls rate with large changes in spectacle correction[17] we suggest that spectacle changes should be limited to less than 1.00DS at any one time in older adults at risk of falls [22] and all older patients should be appropriately warned of the effects of changed refractive error after cataract surgery and/or new spectacles on the apparent position and size of steps and stairs: myopic shifts in refractive error cause steps and other objects to appear smaller and further away and hyperopic shifts cause steps to appear larger and closer.

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Table 1: Mean ± 1 SD Data of Binocular Visual Acuity (logMAR), Binocular Pelli-Robson Letter Log Contrast Sensitivity, TNO Randot Stereoacuity in Log Seconds of Arc and Adaptive gait Parameters (mm) for 10 Older Participants with Optimal Refractive Correction and with +1.00, +2.00, -1.00 and -2.00 Dioptric Blur.

	+2.00 DS	**+1.00 DS**	**Optimal correction**	**-1.00 DS**	**-2.00 DS**
Visual acuity (logMAR)	0.30 ± 0.17[*†‡]	0.05 ± 0.07[*§¶]	-0.11 ± 0.07	0.03 ± 0.07[*§¶]	0.30 ± 0.14[*†‡]
Log Contrast sensitivity	1.76 ± 0.14	1.79 ± 0.13	1.81 ± 0.12	1.80 ± 0.13	1.76 ± 0.14
Log stereoacuity	2.56 ± 0.43[*†‡]	2.17 ± 0.43[§¶]	1.96 ± 0.45[§¶]	2.11 ± 0.39[§¶]	2.53 ± 0.41[*†‡]
Trail foot position before the step (mm)	195.61 ± 34.06[*‡¶]	177.47 ± 44.22[‡¶]	164.57 ± 44.93[§¶]	149.46 ± 38.34[§†]	136.13 ± 41.50[§†*]
Lead foot position before the step (mm)	642.61 ± 51.32	626.39 ± 65.32	600.35 ± 94.71	624.29 ± 46.62	614.96 ± 56.07
Lead horizontal toe clearance (mm)	362.17 ± 51.58[*‡¶]	353.79 ± 35.88[*‡¶]	316.32 ± 38.11[§†¶]	284.28 ± 65.50[§†]	261.51 ± 43.06[§†*]

Trail horizontal toe clearance (mm)	159.49 ± 31.41*‡¶	145.08 ± 28.36*‡¶	121.75 ± 24.50	105.80 ± 25.70§†	95.62 ± 26.92§†*
Trail vertical toe clearance (mm)	26.35 ± 9.16	28.26 ± 10.14	26.89 ± 11.23	24.35 ± 11.41	26.95 ± 17.11
Swing duration (s)	0.60 ± 0.05	0.61 ± 0.04	0.59 ± 0.03	0.60 ± 0.04	0.59 ± 0.04

* significantly different from optimal correction

† significantly different from +1.00DS

‡ significantly different from -1.00DS

§ significantly different from +2.00DS

¶ significantly different from -2.00DS

DS = Dioptres of blur

Figure 1. Mean ± 1 standard deviation data for lead vertical toe clearance (mm) for 10 older participants with optimal refractive correction and with +1.00, +2.00, -1.00 and -2.00 dioptric blur (DS, x axis). The top edge of the raised surface/step is represented at zero mm (y axis). Positive y-axis values correspond to the lead foot stepping higher than the raised surface/step. The dashed line represents hypothetical changes in vertical toe clearance if they were safety driven and due to blurred vision.

Figure 2. Mean ± 1 standard deviation data for lead foot heel position on the step/raised surface (mm) for 10 older participants with optimal refractive correction and with +1.00, +2.00, -1.00 and -2.00 dioptric blur (DS). The edge of the raised surface/step is represented at zero mm. Positive values correspond to the lead foot stepping further onto the raised surface/step. Negative values correspond to the lead foot (heel) hanging off the edge of the raised surface/step.

Figure 1.

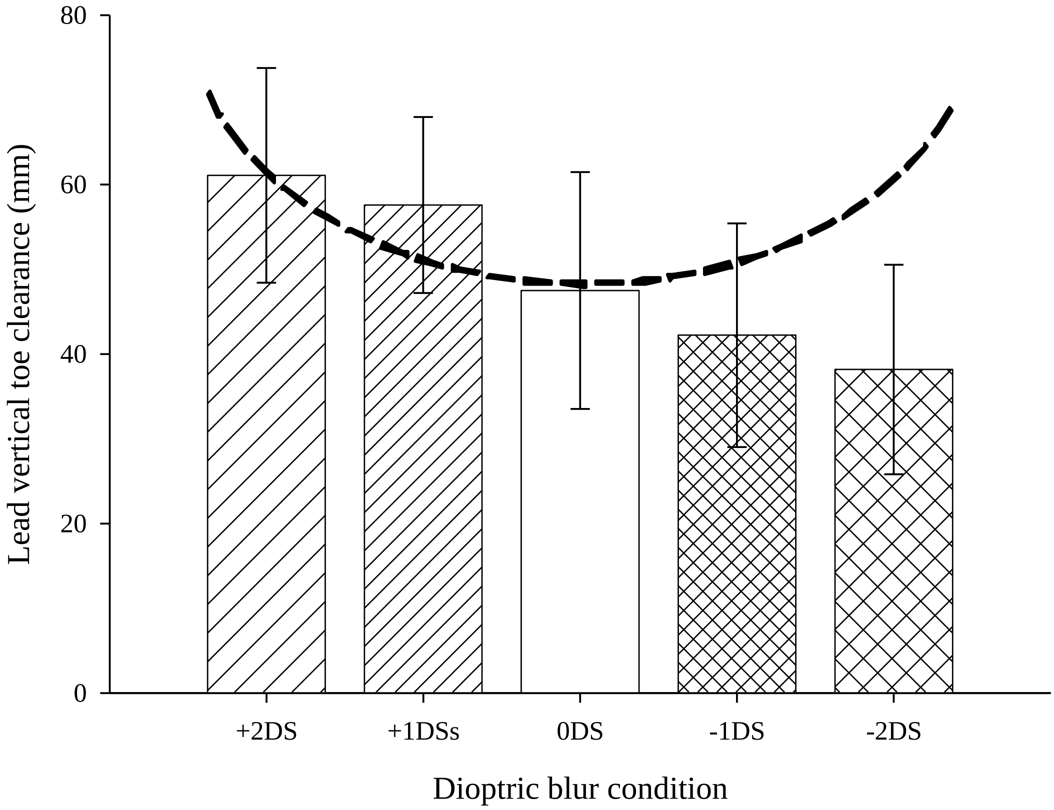
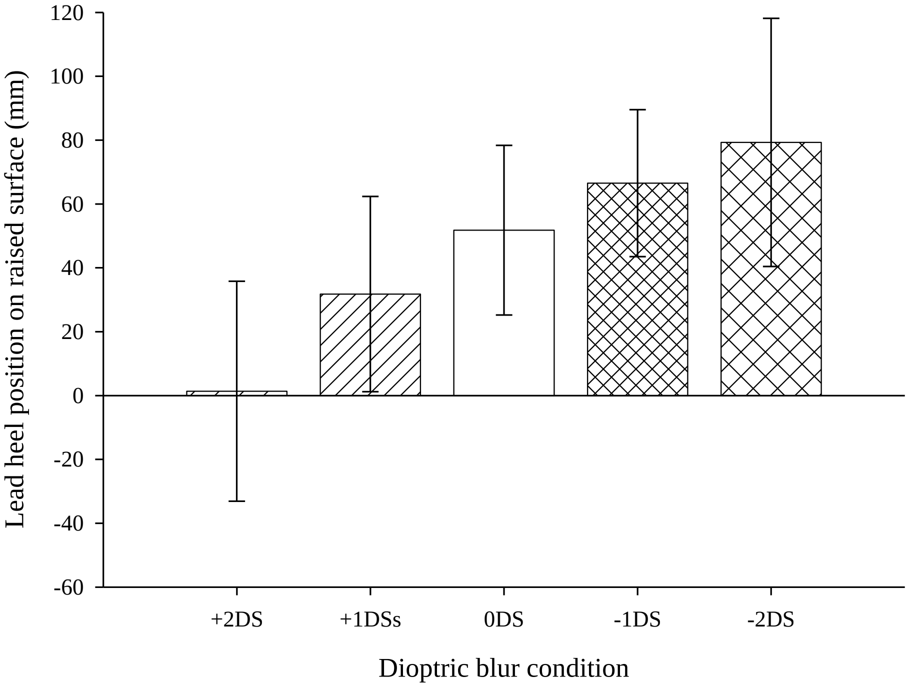

80
60
40
20
0
Lead vertical toe clearance (mm)
+2DS
+1DSs
0DS
-1DS
-2DS
Dioptric blur condition

Figure 2.



120
100
80
60
40
20
0
-20
-40
-60
Lead heel position on raised surface (mm)
+2DS
+1DSs
0DS
-1DS
-2DS
Dioptric blur condition